SOILS, LANDSCAPES, AND GROUND-PENETRATING RADAR ANALYSES OF THE CHIEFLAND LIMESTONE PLAIN IN LEVY COUNTY, FLORIDA

BY

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....dedicated to the memory of my father,
George Edward Puckett.

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Abstract of Thesis Presented to the Graduate School
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SOILS, LANDSCAPES, AND GROUND-PENETRATING RADAR
ANALYSES OF THE CHIEFLAND LIMESTONE PLAIN
IN LEVY COUNTY, FLORIDA

By

William Edward Puckett

May 1990

Chair: Mary Elizabeth Collins
Major Department: Soil Science

This research was conducted to determine and evaluate the soil patterns, soil-landscape relationships, and genesis of the soils on karst in west-central Florida. The study was conducted in Levy County, Florida on the Chiefland Limestone Plain (CLP). The CLP encompassed approximately 28,000 ha of sandy to clayey sediments overlying Eocene-age limestone. The ground-penetrating radar was used to non-destructively study the subsurface features of the CLP. Few relationships existed between the soils and landscapes on the CLP. The soils occurred in patterns so intricate that grid mapping had to be used to delineate map units. A new kind of map unit, the intriplex, was introduced to correctly define the intricacy and apparent randomness of the soils

and landscapes on the CLP. A more efficient method of grid mapping, the flex-grid method, was also introduced and subsequently used by the U.S.D.A. Soil Conservation Service in the progressive soil surveys of all the karst areas in Levy and surrounding counties.

The present CLP surface does not reflect the highly variable paleo-karst nature of the subsurface. The soils formed in Eocene-, Miocene-, Pliocene-, Pleistocene-, and Holocene-aged parent materials that were reworked and deposited on a paleo-karst surface. The abrupt sandy and loamy boundaries between the E and Bt horizons, in the Pleistocene sediments of the CLP soils, were formed by pedogenic processes. The majority of the soils were not formed as a residual product of limestone weathering. Limestone insoluble residues were estimated to accumulate at a rate of 1.5 cm every 40,000 years. The majority of the sediments available for soil formation were derived outside of the CLP area. A flocculation-dispersion mechanism was purposed to explain the occurrence of abrupt boundaries between eluvial and illuvial horizons.

CHAPTER 1
INTRODUCTION AND DESCRIPTION OF STUDY AREA

Introduction

The karst landscapes of west-central Florida have been shaped by sea-level fluctuations and solutional processes. Numerous cycles of marine deposition and subaerial erosion have left an intricate stratigraphy of sands, clays, and limestones. Pedogenic processes in these geologic materials are affected by the initial composition of these sediments and karst processes.

Soil formation by the five soil forming factors (time, parent material, topography, climate, and biota) were described by Dokuchaev (1883) and Jenny (1941). The varied effects of topography, climate, and biota through time on various parent materials are reflected in the multiplicity of soils found throughout Florida. Cooke (1939) listed four factors that are responsible for shaping Florida's landscapes and contributing to the initial composition of sedimentary units: (a) erosion by running water, (b) solution of rocks, (c) work of waves, winds, and currents, and (d) fluctuations of sea level. Karst processes were considered the dominate geologic process controlling Florida's topography (Cooke, 1939; Vernon, 1951; White, 1970).

Soil formation on karst is a dynamic process. The formation of sinkholes and their influence on the soil system have not been extensively studied. Very little research has been conducted on soil patterns and soil-landscape relationships on karst in Florida. Thus, this dissertation will explore the soils and landscapes on karst in west-central Florida.

Description of Study Area

Location

The study area was on the Chiefland Limestone Plain (CLP) in Levy County, Florida (Fig. 1-1). Levy County is bounded on the northwest by the Suwannee River, to the north by Gilchrist and Alachua Counties, to the east by Marion County, to the south by the Withlacoochee River and to the west and southwest by the Gulf of Mexico. The CLP is located in the northwestern part of Levy County. The CLP is divided into northern and southern halves. This study was confined to the northern half of the CLP. A subarea, referred to as the Quincey plot (QP), was selected for more detailed study within the CLP and was located in the northeastern part of the CLP on the farm of Mr. Frank Quincey (Fig. 1-1).

Climate

Levy County is characterized by long, warm summers and mild winters. The average summer temperature was 27^{o}C, the

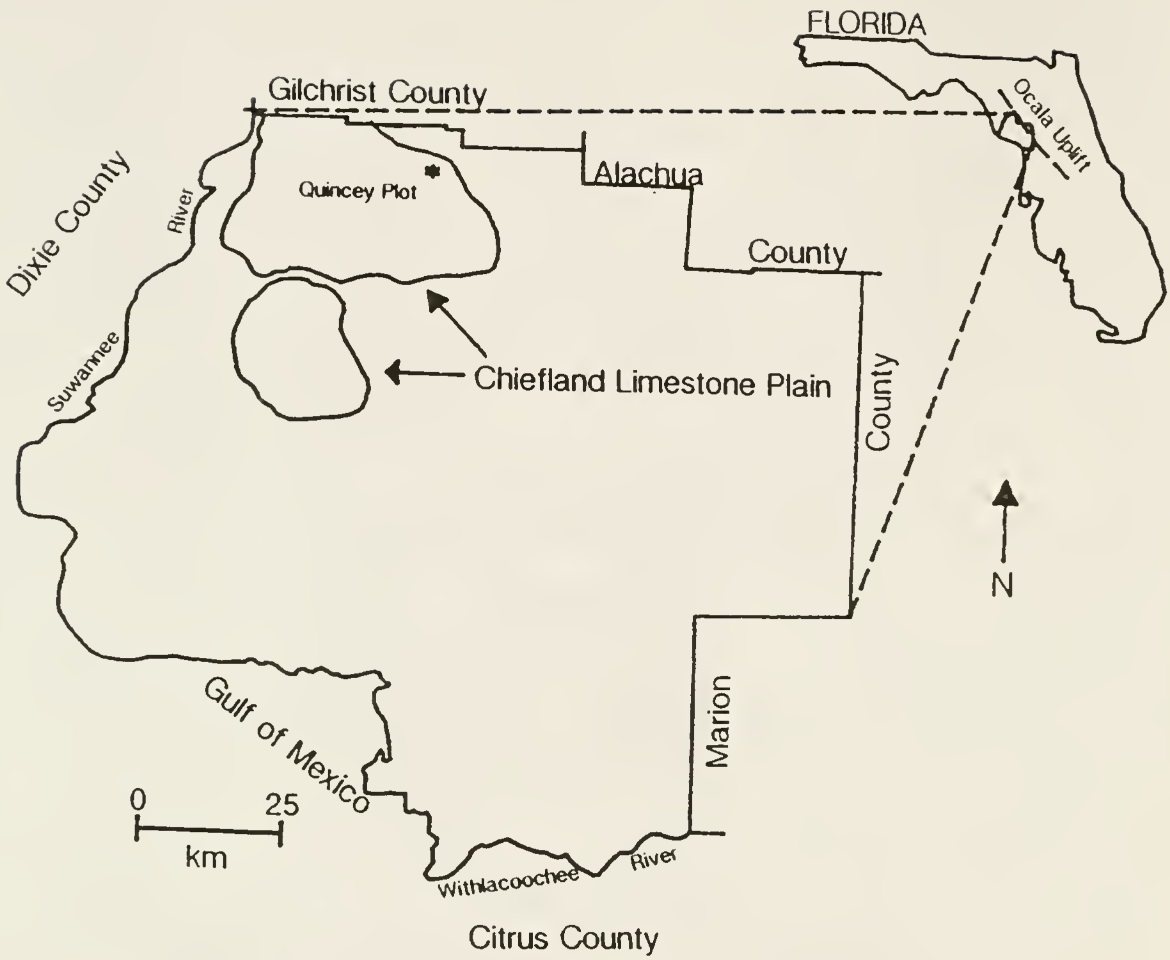


Figure 1-1. Location of the Quincey Plot and the Chiefland Limestone Plain in Levy County, Florida.

average winter temperature was 15^{o}C and the average annual rainfall was 1270 mm from 1841 to 1949 (Vernon, 1951). The average annual temperature was 20^{o}C and the average annual rainfall was 1504 mm from 1962 to 1982 (data collected by the Florida Department of Forestry at the Usher fire tower which was located 2.5 km south of Chiefland, Florida, on U.S. Highway 19). Most of the rainfall occurs during afternoon thunderstorms during the months of June through October. Levy County is located on the Gulf of Mexico and is subject to occasional tropical storms and hurricanes. Extensive flooding can occur along the coastal lowlands during these events.

Levy County is the northern boundary of the hyperthermic temperature regime (Soil Survey Staff, 1975) on the west coast of Florida. The U.S.D.A. Soil Conservation Service in Florida determined that the boundary between thermic and hyperthermic soils, for the purpose of making soil surveys (G.W. Hurt, 1986, personal communication), was the Suwannee River from the Gulf of Mexico to Gilchrist County and then east along the Gilchrist-Levy County line. Brasfield and Carlisle (1976) determined that the boundary between thermic and hyperthermic soils should be moved south to the Withlacoochee River between Levy and Citrus Counties. Vernon (1951) noted that the vegetation was more tropical and lush in Citrus than Levy County and a difference in annual air temperature was evident.

The actual boundary between thermic and hyperthermic soils is not stationary, but probably varies through time and more than likely is better represented as a transitional zone stretching from Gilchrist County to Citrus County. Both thermic and hyperthermic soils were mapped adjacent to each other on the CLP. Soils that were members of established series were mapped as hyperthermic and new series were established as thermic. The new series were established as thermic so they could be used in the progressive soil surveys of adjacent northern counties with similar karst landforms, (i.e., Gilchrist, Dixie and Lafayette Counties).

Drainage

Overland drainage systems are absent on the CLP. Subsurface flow is the dominate drainage mechanism in Levy County (Vernon, 1951). Sandy surfaces and highly porous limestones contribute to the lack of surface drainage.

The Suwannee and Withlacoochee Rivers have few tributaries in Levy County and both are entrenched, in various parts of their courses, into limestone. Numerous springs along the Suwannee River represent release points for much of the rainfall on the CLP (Vernon, 1951; Rosenau et al., 1977). The northern reaches of the Waccasassa River in Levy County flows across thick, clayey alluvial deposits and surface drainage is predominate (Vernon, 1951). When the Waccasassa River floods in this area of Levy County, the

floodwaters flow onto the CLP and slowly disappear into sinkholes. Further south, the Waccasassa River becomes entrenched in limestone and few tributaries are present.

Physiography and Geology

Levy County is part of the Coastal Plain Province as defined by Fenneman (1938) and Thornbury (1965). The Coastal Plain Province is a subaerial inland extension of the continental shelf. The Coastal Plain Province is characterized by sandy to clayey unconsolidated marine and fluvial sediments. Fennenman (1938) and Thornbury (1965) suggested that most of central Florida's topography was controlled, to a large degree, by the presence of soluble limestone.

The Florida peninsula is divided into three physiographic zones (White, 1970). Levy County is located in the mid-peninsular physiographic zone. The mid-peninsular zone extends from approximately Lake City, Florida, to the northern end of Lake Okeechobee. The mid-peninsular zone is characterized by discontinuous parallel ridges separated by broad valleys. Geomorphic subzones are differentiated within the mid-peninsular zone based on elevations. In Levy County, two geomorphic subzones are recognized; the Central Highlands and the Gulf Coastal Lowlands (White, 1970). The Central Highlands are restricted to eastern Levy County. The Gulf Coastal Lowlands occupy the western part at elevations below 33 m.

The Gulf Coastal Lowlands consist of nearly level to gently sloping plains with limestone at or near the surface.

Vernon (1951) subdivided Levy County into two major physiographic areas: the Terraced Coastal Lowlands and the River Valley Lowlands (Fig. 1-2). The Terraced Coastal Lowlands include four coastwise terraces: (a) the Coharie at 66 m, (b) the Okefenokee at 45 m, (c) the Wicomico at 30 m and (d) the Pamlico at 7.5 m. In addition, Healy (1975) added the Silver Bluff terrace at approximately 3 m (Fig. 1-3). Correlations of Florida terraces by several authors are presented in Table 1-1.

The River Valley Lowlands include the alluvium of the Wicomico and Pamlico terraces and Holocene floodplains of the Suwannee and Waccasassa Rivers. Vernon (1951) and White (1970) postulated that the Suwannee River once flowed along the eastern edge of the CLP through the Waccasassa River valley. Vernon (1951) suggested that the Suwannee River might have migrated from the Waccasassa River valley, across the CLP into its present valley. However, Puri et al. (1967) described a topographic high in Gilchrist County which they believed would have kept the Suwannee River from occupying the Waccasassa River Valley.

Several geomorphic subdivisions are identified within the Terraced Coastal Lowlands and River Valley Lowlands (Fig. 1-2). The CLP was one of the geomorphic surfaces defined by Vernon (1951).

Figure 1-2. Physiographic areas of Levy County, Florida (modified from Vernon, 1951).

Legend

TERRACED COASTAL LOWLANDS

Coharie-Okefenokee Terrace
- Brooksville ridge

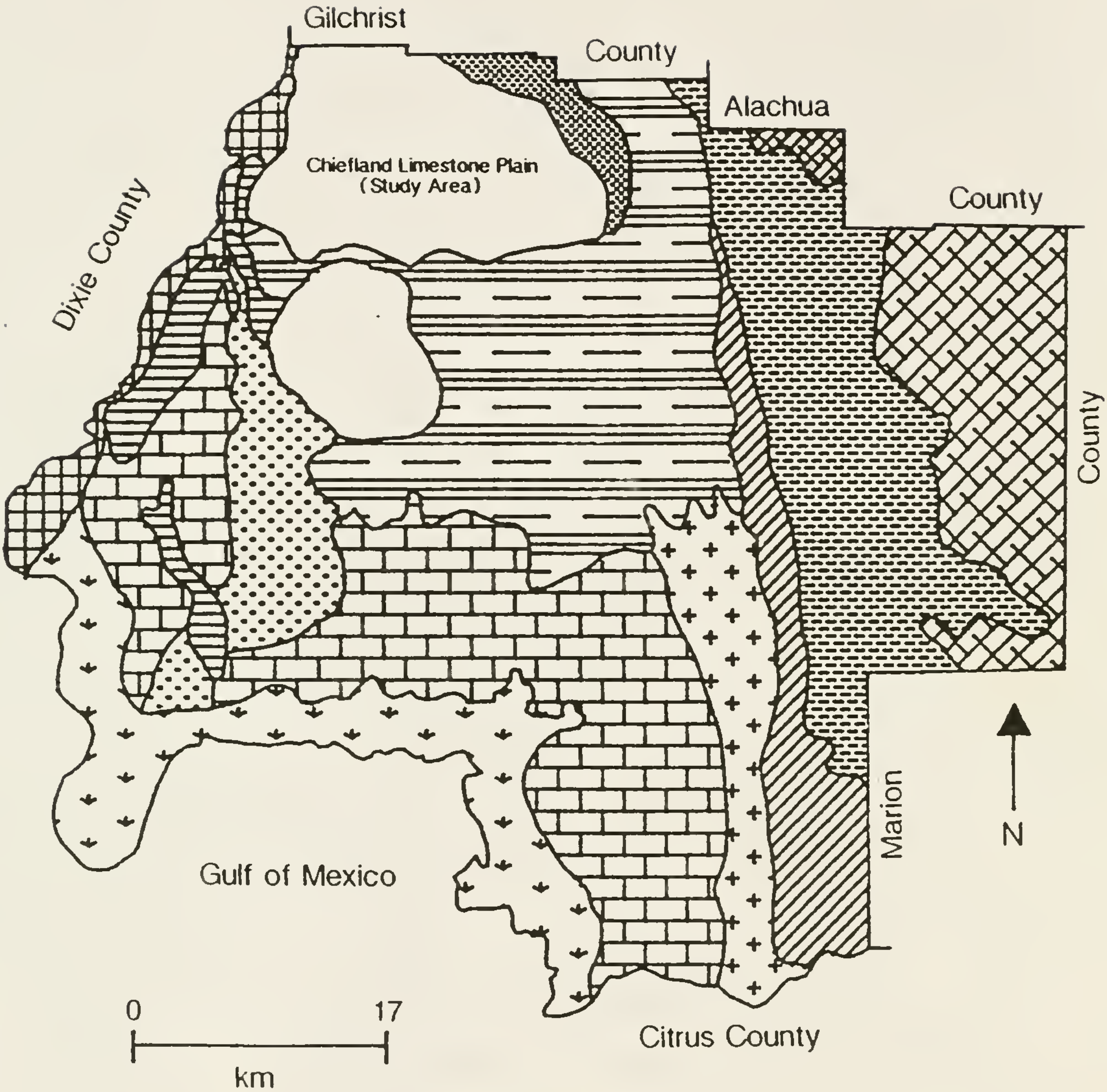
Wicomico Terrace
- Sand belt and coast line
- Chiefland limestone plain

Pamlico Terrace
- Sand belt and coast line
- Limestone shelf and hammocks
- Coastal marst belt

RIVER VALLEY LOWLANDS

Suwannee River Valley Lowland
- Flood plain
- Sand bars of Pamilco formation
- Sand bars of Wicomico formation

Waccasassa River Valley Lowland
- Delta plain of Pamilco formation
- Alluvium of Wicomico formation
- Williston limestone plain



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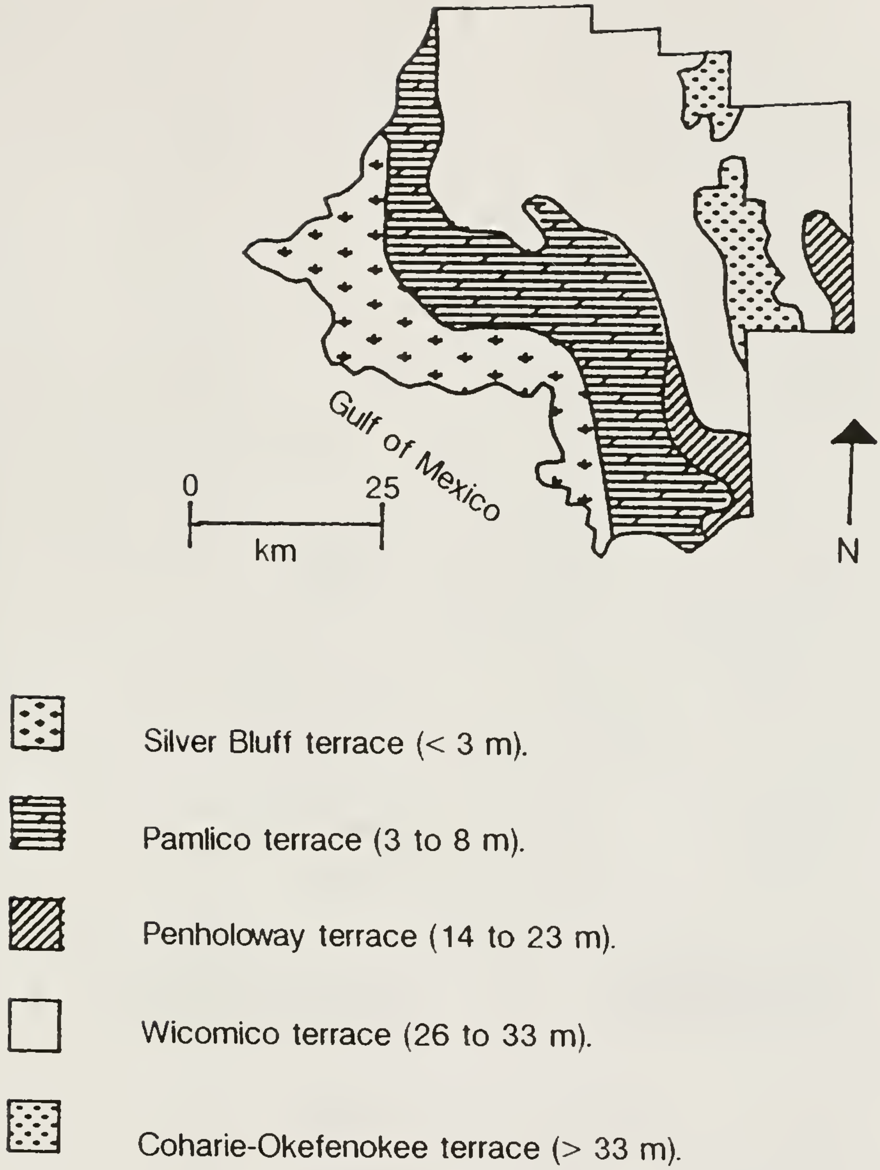


Figure 1-3. Terraces identified in Levy County, Florida (modified from Healy, 1975).

Table 1-1. Correlation of terraces and shorelines in Florida (modified from Healy, 1975).

Cooke 1939,1945 (Statewide)	MacNeil 1959 (Statewide)	Vernon 1951 (Citrus and Levy Counties)	Bermes and others 1963 (Flagler, Putnum, and St.Johns Counties)
Hazlehurst 72-90 m	High Pliocene 50-93 m (subaerial)	--	--
Coharie 57-72 m (marine)	--	Coharie 73 m (marine)	Coharie 57-72 m (marine)
Sunderland 33-57 m (marine)	Okefenokee 50 m (marine)	Okefenokee 50 m (marine)	Sunderland 33-57 m (marine)
Wicomico 23-33 m (marine)	Wicomico 33 m (marine)	Wicomico 33 m (marine)	Wicomico 23-33 m (marine)
Penholoway 14-23 m (marine)	--	--	Penholoway 14-23 m (marine)
Talbot 8-14 m (marine)	--	--	Talbot 8-14 m (marine)
Pamlico 2-8 m (marine)	Pamlico 2-12 m (marine)	Pamlico 2 m (marine)	Pamlico 3-8 m (marine)
Silver Bluff 0-3 m (marine)	Silver Bluff 2-3 m (marine)	--	Silver Bluff 0-3 m (marine)

The CLP is a broad, relatively flat surface of unconsolidated marine sediments overlying the Eocene-age Ocala Group limestones. The surficial sediments of the CLP were associated with the Pleistocene-age Wicomico terrace which was correlated with the Sangamon interglacial period (Cooke, 1939; Vernon, 1951).

Vernon (1951) listed eight agents responsible for the present landscape development in Levy County: (a) warm, humid climate, (b) high annual rainfall, (c) bedrock composed of soluble carbonates, (d) low surface elevations, (e) flat to gently dipping porous rock covered by sand and phosphatic beds, (f) high concentrations of phosphoric, humic, and carbonic acid waters, (g) fracturing along the Ocala Uplift and (h) groundwater. Cooke (1939) listed waves, winds, currents, and the fluctuations of sea level as the primary agents responsible for regional landforms. The agents listed above by Vernon (1951) are also necessary for the development of karst landscapes (Sweeting, 1973; Bloom, 1978).

Karst is a type of topography that is characterized by closed depressions or sinkholes, and is formed by underground solution and diversion of surface waters to underground routes (Soil Survey Staff, 1983). The disappearance of surface waters and its circulation underground is the essence of the karst process as described by Sweeting (1973).

The type of karst on the CLP is normally referred to as "covered karst". Covered karst is where the limestone is covered by soils (Bloom, 1978). Sinclair and Stewart (1985) referred to the CLP karst as "bare or thinly covered limestones" (Fig. 1-4). They defined bare or thinly covered limestones as being covered by materials ranging in thickness from less than 0.3 to about 8 m.

Karst features are common on the CLP. Bowl-shaped depressions and small hills make up the dominate landforms on the CLP. A majority of the depressions are related to karst activity as interpreted from ground-penetrating radar data (G.W. Schellentrager, 1987, personal communication). Most of the bowl-shaped depressions on the CLP would classify as solution sinkholes (Sinclair and Stewart, 1985). Solution sinkholes are formed when lateral variations in solution are minimum.

The depressions vary in diameter from less than 10 m to more than 100 m. Depression sideslopes range from 3 to 12 percent. Minor features on the CLP are the vertically and horizontally oriented solution channels, limestone outcrops, and drowned caves. Elevations range from 8 to 18 m above mean sea level in a SW to NE trend across the CLP.

Two additional Pleistocene terraces were mentioned by Vernon (1951) that may have influenced the topography of the CLP. These were the Talbot at 7 to 14 m and the Penholoway at 14 to 24 m. Vernon (1951) believed that karst activity

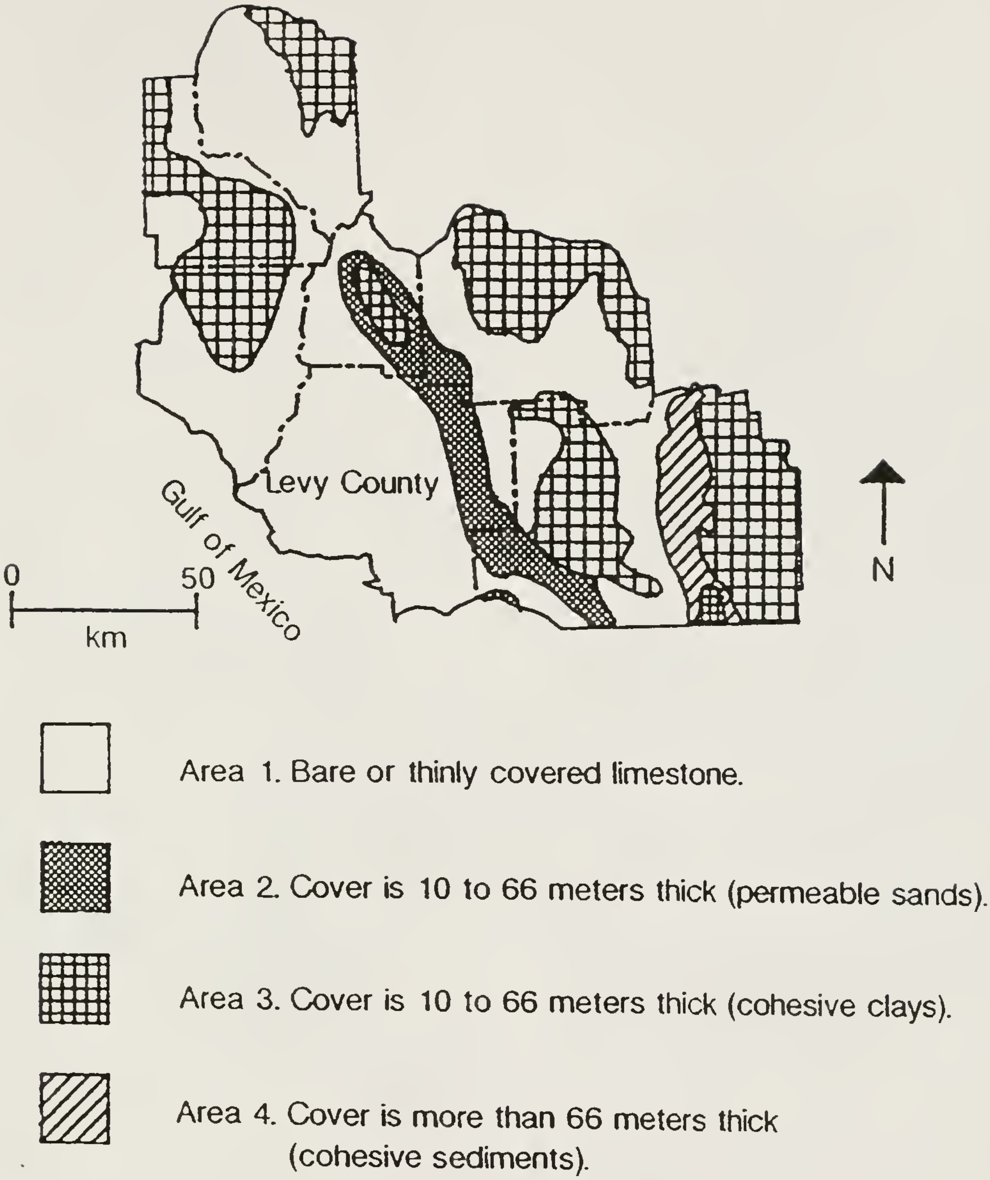


Figure 1-4. Types of karst in west-central Florida (modified from Sinclair and Stewart, 1985).

removed any evidence of these terraces on the CLP. Opdyke et al. (1984) demonstrated how the solution of limestone resulted in isostatic adjustments and subsequent uplift of beach ridges along Florida's Trail ridge. The result of the isostatic adjustments was elevational differences on similar marine terraces. Difficulties arise in assigning Pleistocene shorelines on karst terrains using elevational data because of solutional activity (R.C. Lindquist, 1987, personal communication). Based on elevational and terrain analysis in Alachua, Gilchrist, and Levy Counties, the CLP would be considered part of the Penholoway shoreline (R.C. Lindquist, 1987, personal communication).

Structure

The major structural feature within Levy County is the Ocala Uplift, Fig. 1-1. The Ocala Uplift represents a gentle uplift developed in Tertiary sediments (Vernon, 1951). Cooke (1945) and Vernon (1951) believed that the Ocala Uplift started during Late Eocene to Early Miocene. Pirkle (1956) agreed with Cooke (1945) and Vernon (1951), but Pirkle (1956) believed that the uplift continued during later-Tertiary times. The Ocala Uplift is 434 km long and 113 km wide with the crest of the uplift located in Levy County. The trend of the Ocala Uplift is NW to SE across the central part of the state.

Vernon (1951) was the first to recognize structural faults in Florida. Regional fracture patterns occurred

parallel and perpendicular to the Ocala Uplift (Fig. 1-5). Extensive faulting has been observed in western Alachua County on the Newberry Limestone Plain (Williams et al., 1977). The linear occurrence of sinkholes and caves was attributed to solutional processes occurring along fracture zones. Other major structures recognized by Vernon (1951) included the Bronson graben and Long Pond fault, Fig. 1-5. The Bronson graben was buried by alluvial sediments and may have influenced the course of the Waccasassa River. The Long Pond fault was believed to be responsible for the separation of the CLP into two sections.

Stratigraphy

The oldest rocks identified in Levy County are the Avon Park Limestones of Middle-Eocene age. The Avon Park Limestones are exposed at the surface in southwestern Levy County. Eocene-age limestones form the basic stratigraphic units from which karst has formed in Levy County. The CLP is underlain by Upper-Eocene limestones and younger sediments. Therefore, the discussion in this text will be confined to the Upper-Eocene and younger sediments. Undifferentiated Miocene-, Pliocene-, Pleistocene-, and Holocene-age sands and clays form most of the surficial sediments. The geologic history modified from Vernon (1951) is presented in Table 1-2.

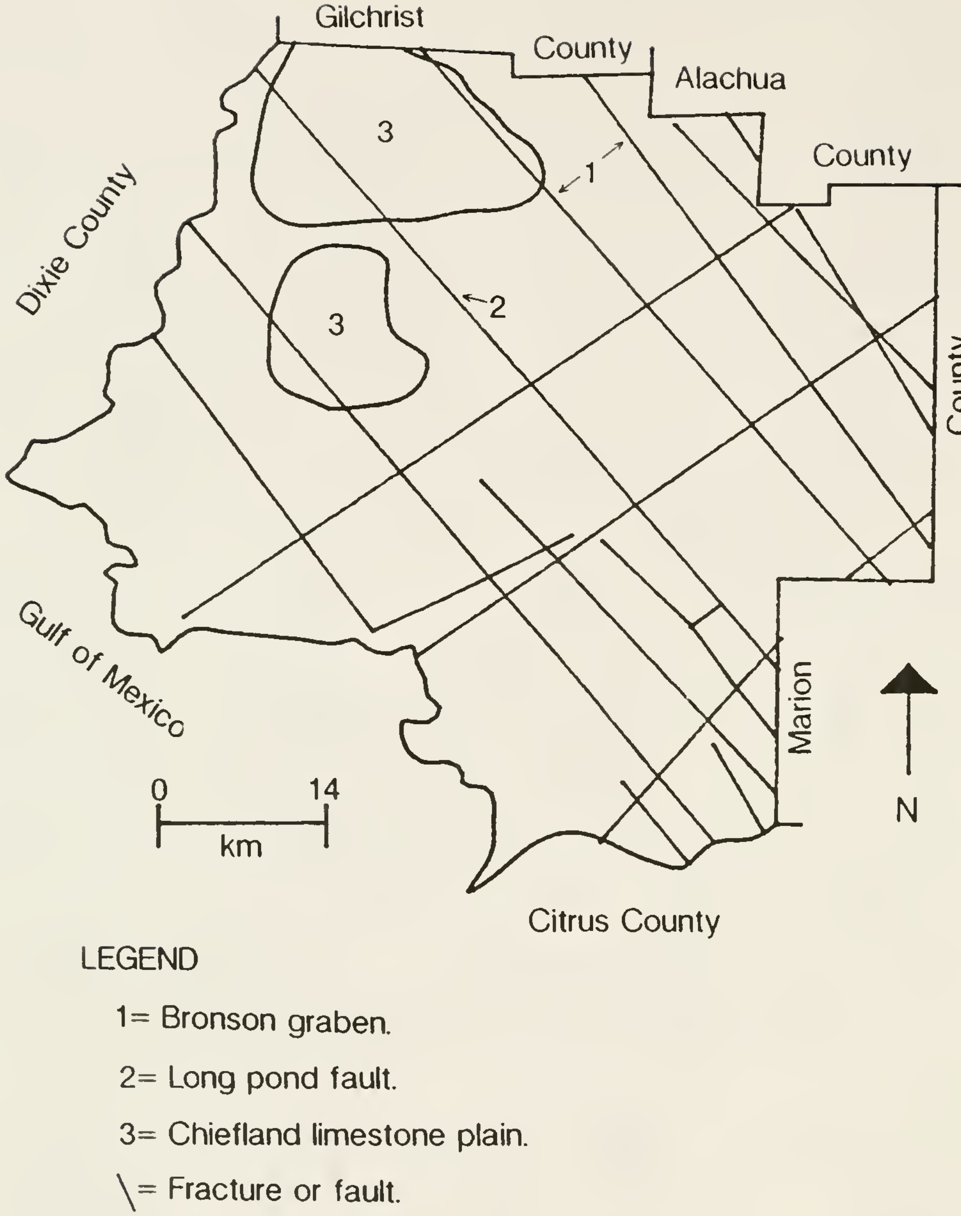


Figure 1-5. Fracture patterns and locations of the Bronson Graben and Long Pond Fault in Levy County, Florida (modified from Vernon, 1951).

Table 1-2. Geologic formations in Levy County, Florida (modified from Vernon, 1951).

Era	Period	Epoch	Formation	
Cenozoic	Quaternary	Holocene	sand, peat and clay, unnamed.	
		Pleistocene	Lake Flirt Marl of late Wisconsin glacial stage.	
			Pamilco formation of Peorian age.	
			Wicomico formation of Sangamon age.	
			Okefenokee formation of Yarmouth age.	
			Coharie formation of Aftonian age.	
	Tertiary	Miocene	Alachua formation (terrestrial) ???—???—??? Hawthorn formation (marine)	
		Oligocene	Absent in Levy County	
		Eocene	Ocala Group Limestones	Crystal River formation
				Williston formation
				Inglis formation

Eocene series

The term "Ocala" limestone was first used by Dall and Harris (1892) after examining an exposure of limestone near Ocala, Florida. The Ocala limestones overlie the Avon Park limestones in all parts of Levy County except in the southwestern corner of Levy County (Vernon, 1951). Vernon (1951) described two formations within the Ocala limestones: (a) the Ocala limestone-restricted and (b) the underlying Moodys Branch Formation. Two members were recognized within the Moodys Branch Formation, the Williston and underlying Inglis. Puri (1953) raised the Williston and Inglis members of the Moodys Branch Formation to "Formational status". He also renamed the Ocala limestone-restricted, the Crystal River Formation. The Ocala limestones are now known collectively as the Ocala Group Limestones. The Ocala Group Limestones, therefore, consist of three formations; the Inglis Formation, the Williston Formation, and the Crystal River Formation. The Crystal River and Williston Formations are the major limestone components of the CLP (Vernon, 1951).

The Ocala Group Limestones are relatively pure (> 98%) calcium carbonate and solutional features are common (Vernon, 1951; Williams et al., 1977). Groundwater freely circulates through this porous limestone which forms the basic hydrologic unit of the Floridan aquifer (Spangler, 1982).

Oligocene series

The Suwannee limestone which represents the Oligocene series was not recognized in Levy County (Vernon, 1951; Crane, 1983). Vernon (1951) proposed that the Suwannee limestones were removed from Levy County by severe erosion.

Miocene to Pleistocene series

The Ocala Group Limestones, in Levy County, are commonly covered by Pleistocene sands or by erosional remnants of the Hawthorn and/or Alachua Formations (Cooke, 1945).

The Hawthorn Formation is predominately associated with the Miocene (Vernon, 1951; Pirkle, 1956; Scott, 1983). The Hawthorn Formation consists of widely varying mixtures of clay, quartz sand, carbonates and phosphates (Scott, 1983). Scott (1983) applied the term F.U.B.A.R. (Fouled Up Beyond All Recognition) to the sediments of the Hawthorn Formation. Variability in the Hawthorn sediments is the rule rather than the exception. The Hawthorn Formation is present in Alachua and Marion Counties (Pirkle, 1956; Williams et al., 1977), but was not recognized in Levy County by Vernon (1951). Cooke (1945) suggested that all of Florida was covered by the Hawthorn sea during Miocene times, but Vernon (1951) believed that Levy County was terrestrial during most of the Miocene due to the Ocala Uplift. Pirkle et al. (1965) reported that the Hawthorn Formation was present throughout most of Florida, except along the crest of the

Ocala Uplift. Erosional remnants of the Hawthorn Formation were probably present over the crest area of the Ocala Uplift in Levy County. Several coral heads of Siderastraea siderea, were discovered in a sinkhole near Chiefland, Florida. This species of coral has been associated with the presences of the Hawthorn sea in western Alachua County (Pirkle, 1956; Williams et al., 1977). Transportation of these coral heads by former ocean currents may have been responsible for the location of the coral heads on the CLP.

The Alachua Formation is composed of clays, sands, rubble of phosphatic rock, silicified wood, and limestone rubble (Vernon, 1951). The Alachua Formation was identified in eastern Levy County (Vernon, 1951) and on a small area of the CLP (Vernon, 1951; Crane, 1983). Cooke (1945) considered the Alachua Formation as the collapsed and compacted residue of the Hawthorn Formation. Vernon (1951) correlated the Alachua Formation as a contemporaneous terrestrial component associated with the Hawthorn Formation. Pirkle (1956) considered that the Alachua Formation consisted of terrestrial deposits which accumulated at intervals during Early Miocene, Pliocene, and Pleistocene times. Pirkle (1956) considered the Hawthorn Formation the source of phosphorus in the Alachua Formation.

Williams et al. (1977), considered the Alachua Formation a terrestrial residual of the Hawthorn Formation.

Objectives of Study

The objectives of this research were; (a) to map, characterize, and classify the soils on the CLP as part of the progressive soil survey in Levy County, (b) combine GPR technology and grid mapping to better determine map unit type and composition, and (c) provide information on soil-landscape relationships (Chapter 2); (d) develop "relationships" between the graphic GPR profiles and the soils on the CLP, and (e) qualify the spatial characteristics of the soils identified using the GPR (Chapter 3); (f) determine the origins of the soils on the CLP, (g) propose a parent material-time sequence model, and (h) propose genetic pathways for soil genesis on the CLP (Chapter 4).

CHAPTER 2
RADAR AND FLEX-GRID ANALYSIS OF SOILS ON THE CHIEFLAND LIMESTONE PLAIN

Introduction

The landscapes of west-central Florida have been shaped by sea-level fluctuations and karst processes (Cooke, 1939). The CLP located in Levy County, Florida, exhibits characteristics of these processes (Vernon, 1951). Karstsification has created an irregular bedrock subsurface while Pleistocene sea-level changes have deposited and reworked the surficial sediments. The resultant surface is nearly level to gently rolling with numerous sinkholes. Depth to limestone and diagnostic subsurface horizons exhibit extreme variations within short horizontal distances. Relationships between soils and landscapes on this karst terrain are not well understood and delineation of soil map units based on soil-landscape relationships is difficult.

Variation between soil occurrence and landscape position in any terrain can be classified as either systematic or random (Wilding and Drees, 1983). A systematic relationship occurs when soils can be predicted based on geomorphic-relationships. A random relationship

would exist when such a prediction about soils and landscapes is not possible.

Soil scientists normally rely on systematic variations in soils and landscapes to design and delineate map units that describe how the soils and landscapes are related. The type of map unit (i.e., complex, consociation, etc. (Soil Survey Staff, 1983)) depends on the scale of mapping and its subsequent use. After the map units are delineated, a percentage of the map units should be transected to determine the percentage of component soils. Component soils are defined in this text as the soils identified in the map unit.

Johnson (1961) described two transect methods, line- and point-intercept, for estimating the composition of map units. These methods are based on whether map unit boundaries and/or component soil boundaries can be identified within a landscape.

The line-intercept method is used when component soil boundaries are easily observed within map unit boundaries. A soil scientist can walk across the landscape and estimate the composition of the map unit based on changes of geomorphic features.

The point-intercept method is used when map unit boundaries can be delineated within a landscape but component soil boundaries are not apparent within the map unit delineation. The point-intercept transect is conducted

with observation points at pre-selected intervals within the map unit. The point-intercept method has been used successfully in various terrains (Powell and Springer, 1965; Steers and Hajek, 1979; and Schellentrager et al., 1988).

Lack of soil and landscape relationships in karst terrains are normally expected (Sweeting, 1973). But, when soils and landscapes vary independently of each other, (i.e., karst terrain in Florida), map unit boundaries and, therefore, component soils are not easily determined. Soil survey techniques in areas where soil and landscape relationships are not apparent normally depend on labor intensive "grid-mapping" procedures. Grid-mapping involves observing soils at predetermined intervals along parallel traverse lines and drawing boundaries between observation points in order to separate map units. Transects may or may not have to be conducted to supplement the information obtained using the grid method of mapping.

Ground-penetrating radar (GPR) can be used to supplement grid mapping in terrains where soils and landscapes vary independently. Ground-penetrating radar has the advantage of providing a continuous graphical display of diagnostic soil horizons below the surface (Johnson, et al., 1980; Doolittle, 1982; Collins et al., 1986; Collins and Doolittle, 1987; Schellentrager et al., 1988) and, therefore, does not require the assumption of soil homogeneity between observation points.

Ground-penetrating radar has been used to investigate soil variability and composition in several physiographic areas in Florida (Shih and Doolittle, 1984; Shih et al., 1985; Collins et al., 1986; Collins and Doolittle, 1987; Schellentrager et al., 1988). None of these studies concentrated on mapping and transecting procedures in karst areas; nor did they evaluate the effectiveness of incorporating GPR and grid mapping techniques into an on-going soil survey. The objectives were to (a) combine GPR technology and grid mapping to better determine map unit type and composition and (b) provide information on soil-landscape relationships. Arnold (1988) considered the study of soil-landscape relationships to be more intensive during progressive soil surveys than most other types of soil-landscape research. Because of this, the study was conducted in conjunction with the on-going soil survey in Levy County, Florida.

Material and Methods

Location of Study Area

Levy County is located on the west coast of peninsula Florida (Fig. 1-1). The mean annual temperature is 21°C and the average annual rainfall is 1387 mm. The study area was located on the CLP. Elevations range from 8 to 20 m, above mean sea level, in a SW to NE trend across the limestone plain. The CLP encompassed approximately 28,000 ha.

Physiography and Geology

Levy County is part of the Coastal Plain Province as defined by Fenneman (1938) and Thornbury (1965). The Coastal Plain Province is characterized by sandy to clayey unconsolidated marine and fluvial sediments. Vernon (1951) subdivided Levy County into two major physiographic areas; the Terraced Coastal Lowlands and the River Valley Lowlands. The CLP is part of the Terraced Coastal Lowlands (Fig. 1-2). The Terraced Coastal Lowlands include four coastwise terraces; (a) the Coharie at 66 m, (b) the Okefenokee at 45 m, (c) the Wicomico at 30 m, and (d) the Pamlico at 7.5 m (Fig. 1-3).

The CLP is a broad, relatively flat, surface of unconsolidated marine sediments overlying the Eocene-age Ocala Group limestones. The CLP was described by Vernon (1951) to be a submarine limestone shelf formed as part of the Wicomico shoreline. However, evidence from Alachua, Gilchrist, and Levy Counties suggested that the CLP should be considered part of the Penholoway shoreline (R.C. Lindquist, 1987, personal communication). The Wicomico and Penholoway terraces were both correlated with the Sangamon interglacial period (Cooke, 1939 and Vernon, 1951).

The type of karst on the CLP is normally referred to as "bare or thinly covered limestone", Fig. 1-4, (Sinclair and Stewart, 1985). They defined bare or thinly covered

limestone as being covered by sediments ranging in thickness from less than 0.3 to about 8 m.

Karst features are common on the CLP. Bowl-shaped depressions and small hills create the dominant landforms. Most of the bowl-shaped depressions are classified as solution sinkholes (Sinclair and Stewart, 1985). Solution sinkholes are formed when lateral variations in solution are minimum. The depressions caused by the sinkholes vary in diameter from less than 10 m to more than 100 m. Slopes into these depressions ranged from 3 to 12 percent. Slopes of the small hills ranged from 4 to 6 percent. Minor features of the CLP are vertically and horizontally oriented solution channels, limestone outcrops, and drowned caves.

Undifferentiated Miocene-, Pliocene-, Pleistocene-, and Holocene-age sands and clays blanket the Ocala Group limestones.

Initial Soils Legend

A preliminary field study was conducted to evaluate the soil and landscape relationships on the CLP. Soil surveys from Alachua (Thomas et al., 1985) and Marion (Thomas et al., 1979) Counties, which have similar karst areas, were used to provide initial soil and landscape data. Reconnaissance soil mapping across the CLP was used to gather soil and landscape information. The minimum-size delineation for the survey was established at 2-ha based on the 1:24000 mapping scale.

GPR System

The GPR system used was the Subsurface Interface Radar (SIR) System-8 (The trade name has been used to provide specific information. Its mention does not constitute endorsement). The 120-MHz antenna was towed at a speed of 4.0 to 5.5 km/hr. The scanning time of the GPR was 70 ns, with a scanning rate of 25.6 scans/s.

Flex-Grid Mapping and GPR Transect Information

A flex-grid system of mapping was developed where grid-interval varied according to soil complexity. The grid-interval of the flex-grid survey was not fixed but was allowed to vary according to the complexity of the map unit. Observation intervals within the flex-grid, ranged from 30 to 200 m.

The flex-grid method was devised after the traditional grid-method (fixed interval) was unsuccessful in correctly identifying the complexity of soil map units. Ground-penetrating radar data confirmed the failings of the traditional grid-method to identify map unit complexity. Traditional grid-methods would have been successful with the use of GPR transects, but because the grid-interval was fixed, it was more laborious than the flex-grid system. The primary goal of the flex-grid survey was to locate map unit boundaries. The GPR was used to determine the periodicity of the soils or composition. Some soil scientists (Wilding and Drees, 1983) have expressed concern that grid surveys

may not properly delineate map units due the coincidence of the grid interval with the periodicity of the soils. Since the grid interval of the flex-grid survey was not constant, errors associated with soil periodicity were reduced. The flex-grid system was used to locate areas of modal soil components and the GPR was used to determine the complexity of the soils within these areas.

The GPR graphic profiles were used to check map unit boundaries, determine the linear regularity of diagnostic subsurface features, and determine map unit composition. Criteria to separate map units were soil drainage, depth to Bt horizon, and depth to limestone. These soil characteristics were determined to have a major influence on the soil use and interpretations for the survey area.

Each GPR transect was 305 m long; observational markers were placed at 10 equally-spaced points. One to three soil borings were made along each transect in order to collect field notes (i.e., diagnostic horizons, colors, textures, drainage, and depth to limestone) needed to scale the radar imagery. The difference between the scaled radar images and actual depths to subsurface features as determined by soil borings ranged from 3 to 20 cm. This range is in agreement with findings by Johnson et el. (1980), Shih et al. (1985), and Zobeck et al. (1985).

Justification and Definition of Intriplex Map Unit

A map unit is "a collection of areas defined and named the same in terms of their soil components or miscellaneous areas or both" (Soil Survey Staff, 1981). Map units are designed to meet certain taxonomic and interpretative criteria. Kinds of map units (i.e., consociation, complex, association, and undifferentiated groups) used in a soil survey depends on the soil patterns and the purpose and proposed intensity of the survey. The mapping scale of the soil survey is a primary factor in determining the kind of map unit selected.

Properly designed map units convey characteristics about the soils and landscapes to the soil survey user. Soil areas delineated as a complex map unit indicate that two or more soil components occur in a regularly repeating pattern so intricate that the soil components cannot be separated at the selected scale of mapping (Soil Survey Staff, 1983). An undifferentiated group is used when two or more soil components do not occur in a regularly repeating pattern, but because of some common limitation (i.e., steepness, stoniness, or flooding) which limits use and management, the soils are combined (Soil Survey Staff, 1983). The major soil components of an undifferentiated group are generally large enough to be separated at the scale of mapping. However, when soils and landscapes do not occur in a regularly repeating pattern and delineations are

not limited by a common feature, a gap exists in the kind of map units available for interpreting soil surveys. To refer to such soil areas as complexes, no doubt conveys an idea of "intricacy" of soils to the layperson, but to a soil scientist it probably conveys the concepts defined in the National Soils Handbook (Soil Survey Staff, 1983).

In the karst regions of west-central Florida, another kind of map unit is purposed to bridge the gap between complexes and undifferentiated groups. The new kind of map unit is termed "Intriplex", a combination of the word "intricate" and "complex".

Intriplex map units are similar to complexes except for the requirement that the soil and landscapes occur in a regular repeating pattern. Soil intriplexes are map units that consist of areas of two or more kinds of soils (taxa) or miscellaneous areas that are so intricately associated that they appear to occur at random. Individual components would be difficult to delineate even with intensive onsite investigations. The proportions of the major components vary from one delineation to another but each occupies a significant part of the delineation. Grid mapping is normally required to delineate components of intriplexes. Transects are conducted within selected delineations to determine the composition of component soils. No one soil dissimilar to the named components is to exceed 10% of the whole and the aggregate of dissimilar soils can not be more

than 25%. Intriplexes are usually named using soil series names, although other taxonomic class names and names of miscellaneous areas can be used. Interpretations for some uses may be made for the intriplex as a whole, determined by the overriding limitation of any one component. For some other land uses, each component of the intriplex is interpreted separately. This definition is based on and modified from the definition of a complex in the National Soils Handbook (Soil Survey Staff, 1983).

Statistical Analysis

The mean was calculated for the component soils and the confidence interval and coefficient of variation were calculated for each map unit according to the method outlined by Arnold (1979, 1980). The data were not tested for normality due to the assumption that a binomial distribution tends toward normality as the sample size is increased (Snedecor and Cochran, 1967). The calculated statistics are based on a binomial distribution, where the named and similar soils make up one population and the dissimilar soils make up another population. Bigler and Liudahl (1984) tested this method of determining map unit composition in North Dakota and concluded that it was rapid and reliable. The method was also used in Florida by Schellentrager et al., (1988).

Results and Discussion

Initial Soils Legend

The initial soils legend which was established based on soil surveys from neighboring counties and reconnaissance mapping within the CLP is presented in Table 2-1. The classification of these soils is also presented in Table 2-1. The Arrendondo, Cadillac, and Millhopper soils are defined as having A and E horizons greater than 1 m in combined thickness. Arrendondo and Millhopper soils are both Ultisols that normally occur in non-karst landscapes. Arrendondo soils are well drained and have coated (Soil Management Support Services, 1987) sands between a depth of 25 and 100 cm. Millhopper soils are moderately-well drained and are uncoated (Soil Management Support Services, 1987). Cadillac soils are well drained and are formed on karst landscapes. Cadillac soils are Alfisols with 7.5YR colors throughout the Bt horizon. Arrendondo, Cadillac, and Millhopper soils are mapped within the same landscapes in Alachua and Marion counties.

Candler and Tavares soils both have sandy profiles and are uncoated. Candler soils are excessively-well drained and have lamella normally between a depth of 150 to 200 cm. Tavares soils are moderately-well drained and lack lamella.

Hague, Jonesville, and Pedro soils have Bt horizons at depths less than 100 cm and are well drained. Hague soils

Table 2-1. Classification of series used in the initial soils legend for the Chiefland Limestone Plain.

Series	Family Classification
Arrendondo	Loamy, siliceous, hyperthermic Grossarenic Paleudults
Cadillac	Loamy, siliceous, hyperthermic Grossarenic Paleudalfs
Candler	Hyperthermic, uncoated Typic Quartzipsamments
Hague	Loamy, siliceous, hyperthermic Arenic Hapludalfs
Jonesville	Loamy, siliceous, hyperthermic Arenic Hapludalfs
Millhopper	Loamy, siliceous, hyperthermic Grossarenic Paleudults
Pedro	Fine-loamy, siliceous, hyperthermic shallow Typic Hapludalfs
Tavares	Hyperthermic, uncoated Typic Quartzipsamments

are defined as having a Bt horizon between depths of 50 and 100 cm, hue of 7.5YR somewhere within the Bt horizon, and a decrease in clay content with depth. Hague soils occur in both karst and non-karst landscapes. Jonesville soils have a Bt horizon between 50 and 100 cm overlying limestone. The Pedro series was established as having a cyclic, discontinuous Bt horizon over limestone that occurred at depths less than 50 cm. Hague soils are mapped normally as consociations. Generally, Jonesville and Pedro soils are mapped as complexes.

Soil-Landscape Model

A soil-landscape model for mapping the CLP was conceptualized based on the preliminary field study using the initial soils legend (Fig. 2-1). The Typic Quartzipsamments (Candler and Tavares soils) were conceptualized to occur predominately on elevated positions where eolian sands had accumulated and in depressional areas where sands had collected due to subsurface collapse. The Grossarenic Paleudults and Paleudalfs (Arrendondo, Cadillac, and Millhopper soils) occurred on the broad level areas where slopes ranged from 1 to 5 percent. The matrix of the CLP was composed of this type of terrain. The Paleudults developed in leached parent materials which were not influenced by the deeper underlying limestone. The Hapludalfs (Hague, Jonesville, and Pedro soils) occurred

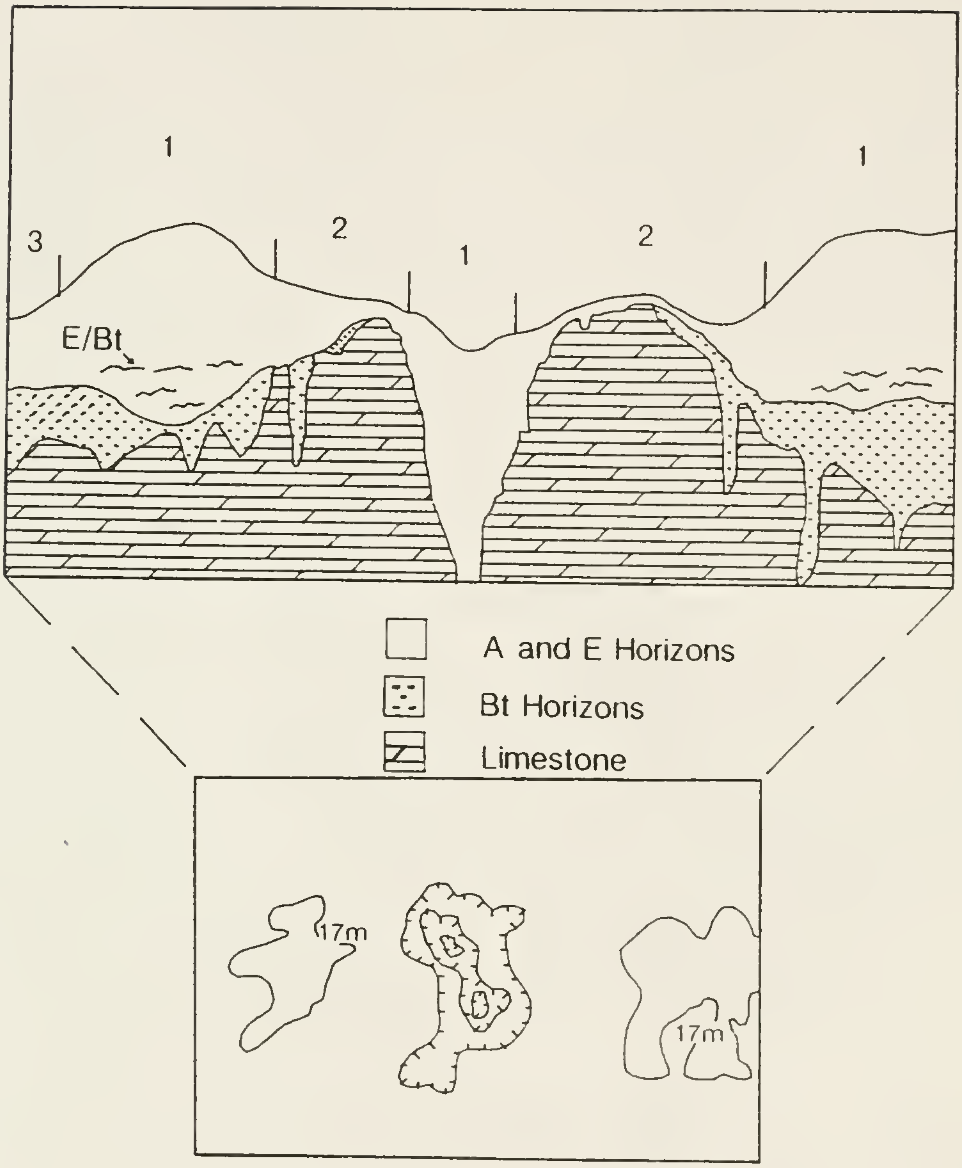


Figure 2-1. Conceptual soil-landscape model for the Chiefland Limestone Plain based on the initial soils legend. (1=Typic Quartzipsamments; 2=Typic, Lithic, and Arenic Hapludalfs and Lithic Quartzipsamments; and 3=Arenic Hapludalfs).

where limestone was nearer to the surface, i.e., such as the rim areas around sinkholes.

The initial mapping model separated the Typic Quartzipsamments, Grossarenic Paleudults, and Grossarenic Paleudalfs as consociations (Soil Survey Staff, 1983) and the Arenic and Typic Hapludalfs as complexes (Soil Survey Staff, 1983).

Field mapping was initiated based on the initial soils legend and the conceptual soil-landscape model. An immediate conclusion was that the soils and landscapes of the CLP were not occurring systematically. The landscapes could be delineated but the soils could not be predicted based on landscape position. Therefore, a grid mapping procedure was used to provide additional data in order to delineate the boundaries between soil map units across landscapes.

<u>Grid Mapping</u>

A soil map based on the initial soils legend and grid mapping is presented in Fig. 2-2b. Elevations in this selected 260-ha study area (section 21, R15E, T11S, Trenton USGS quadrangle) ranged from 12 to 20 m (Fig. 2-2a). One hundred and one borings were made in this study area and map unit boundaries were delineated based on the grid borings. A summary of the grid data is provided in Table 2-2.

Cadillac variant was the dominate soil in map unit 12 according to the grid data. The Cadillac soils were

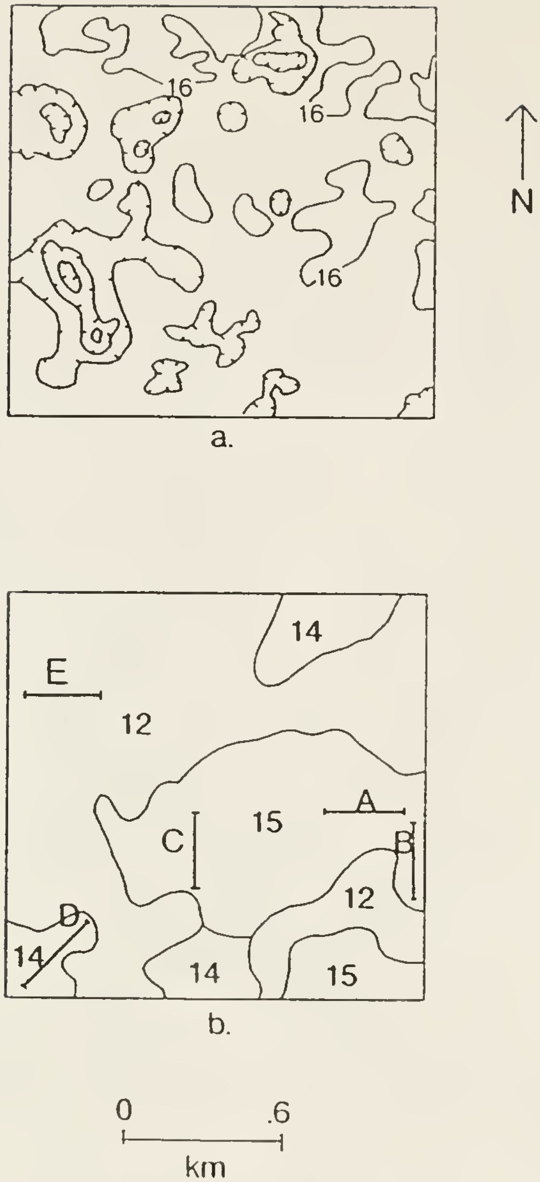


Figure 2-2. Soil map, ground-penetrating radar (GPR) transect locations, and topographic map (based on USGS topoquad) of the 260-ha study area on the Chiefland Limestone Plain.
a) Topographic map of the 260-ha study area based on the USGS topoquad (1.5 m contour).
b) Soil map (12-Cadillac variant soils; 14-Hague variant and Typic Hapludalfs; and 15-Candler soils) and GPR transect locations indicated by letters.

Table 2-2. Summary of grid data for 260-ha area on the Chiefland Limestone Plain.

	Dominant soils and similar soils		
Map Unit	Cadillac Variant	Candler	Hague Variant and Typic Hapludalfs
	------------no. of observations------------		
12	54 *(90)	6 (10)	0
14	1 (7)	0	14 (93)
15	3 (12)	23 (88)	0

*Percent of named plus similar soils.

determined to be variants due to drainage and color. Depth to limestone in this unit was generally below 200 cm. Arrendondo and Millhopper soils were not identified in map unit 12. Cadillac Variant soils occurred on all landscape positions but were generally located on the nearly level landscapes.

Map unit 14 was mapped as a complex of Hague Variant and unnamed Typic Hapludalfs. Hague was a variant due to high clay contents in the Bt horizon and the occurrence of limestone within 200 cm. The Typic Hapludalfs had characteristics similar to the Hague Variant except that the Bt horizons were within 50 cm of the soil surface. The Typic Hapludalfs and Hague Variant soils occurred adjacent and in depressions on the landscape and also on the nearly level areas where map unit 12 normally occurred. Jonesville and Pedro soils were of minor extend in this map unit.

Candler and similar soils made up 88 percent of map unit 15 and were represented as a consociation based on the grid data. The map unit delineated as Candler soils contained most of the isolated "hills" that occurred on the nearly level topography (Figs. 2-2a and 2-2b). These hills could have been the product of eolian processes. Tavares soil did not occur in the study area.

The conceptual soil-landscape model was correct in some cases but it could not be applied in all cases. One reason the model could not be applied directly might be due to the

nearly level topography and variable subsurface features of the CLP.

GPR Analysis

As a final check, 5 GPR transects were conducted within the map units that had been delineated in the 260-ha study area. Ground-penetrating radar transect locations are given in Fig. 2-2b. In these areas, GPR investigations illustrated that the subsurface variability of the Bt horizons was much greater than had been observed by the grid mapping procedure (Fig. 2-3). Areas where the proposed consociations were expected to occur were complexes.

Transects A, B and C were conducted within the proposed Candler map unit (Table 2-3). Transect A was conducted across the footslope, sideslope, shoulder slope, and summit of a small hill with elevations ranging from 16 to 18 m as determined from the USGS topographic map. Transect B was conducted parallel to the summit of a narrow hill at an approximate elevation of 20 m. Transect C was across a nearly level area of the Candler map unit. In contrast to the grid results, the average of the three transects was 50 percent Cadillac Variant and similar soils and 47 percent Candler and similar soils.

Transect D was conducted across a depressional area within the Hague map unit. The results were 50 percent Cadillac Variant and similar soils and 50 percent Hague Variant, Typic Hapludalfs, and similar soils. According to

Figure 2-3. Ground-penetrating radar graphic profile illustrating the subsurface variability of the Bt horizons in soils on the Chiefland Limestone Plain.

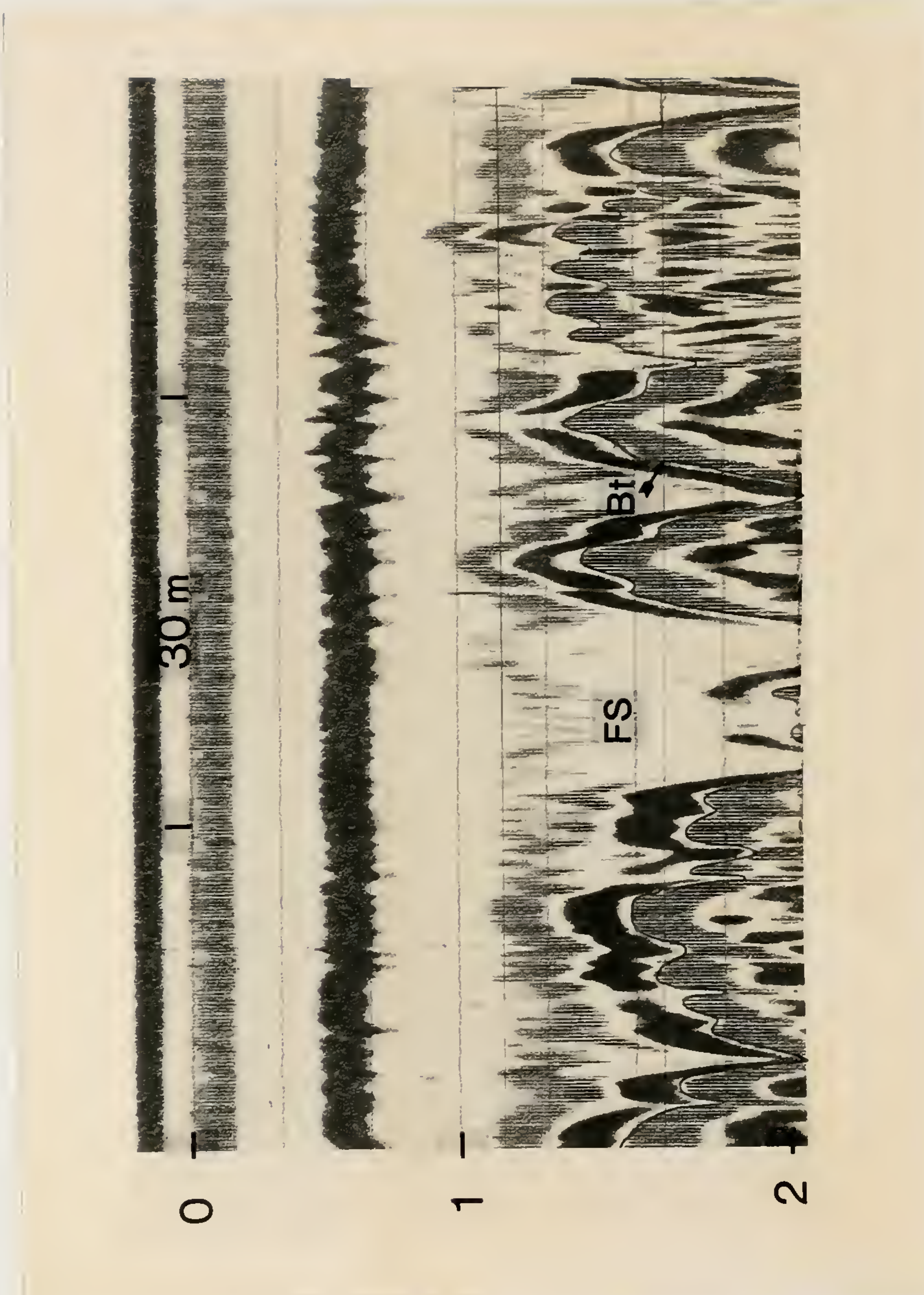

30 m
FS
Bt
0
1
2

Table 2-3. Summary of ground-penetrating radar transect data for the 260-ha selected study area on the Chiefland Limestone Plain.

# GPR Transect	Dominant soils and similar soils		
	Cadillac Variant	Candler	Hague Variant and Typic Hapludalfs
	---------------------	%	---------------------
A	60	40	0
B	30	70	0
C	60	30	10
D	50	0	50
E	50	50	0

Ten observations stations per transect.

the transect information, a Grossarenic soil component would need to be added to map unit 14.

Transect E was conducted across a depressional area within the Cadillac map unit. Fifty percent of the transect was Cadillac Variant and similar soils and 50 percent was Candler and similar soils.

Based on the data presented for the 260-ha area plus GPR transect information from other areas, map units 15 and 12 were combined due to the inconsistency with which they could be separated. Another interesting result was the comparison of the grid data for the 260-ha area and the GPR transect data (Table 2-4). The grid data supported map units 12 and 15 as consociations and map unit 14 as a complex. But the GPR data suggested that map units 12 and 15 be combined and map unit 14 remain a complex but with an additional Grossarenic soil component. The grid results were based on 101 observations and the GPR results were based on 50 observations for this area. The average grid density was 1 observation for every 2.4-ha. Data from the GPR transects were taken every 30.5 m along a 305 m transect.

The grid data covered the entire area but spacing probably was too wide to accurately reflect subsoil variations. Three additional 260-ha grid plots were sampled for grid analysis. A summary of the grid data for the three plots plus the previous plot is given in Table 2-5, (map

Table 2-4. Comparison of grid data and ground-penetrating radar transect data for the selected 260-ha study area on the Chiefland Limestone Plain.

Map Unit	Dominant soils and similar soils					
	Cadillac Variant		Candler		Hague Variant and Typic Hapludalfs	
	Grid	GPR	Grid	GPR	Grid	GPR
	------------no. of observations------------					
12	54 *(90)	5 (50)	6 (10)	5 (50)	0	0
14	1 (7)	5 (50)	0	0	14 (93)	5 (50)
15	3 (12)	15 (50)	23 (88)	14 (47)	0	1 (3)
Total	58 (57)	25 (50)	29 (29)	19 (38)	14 (14)	6 (12)

* Percent of named plus similar soils.

Table 2-5. Summary of grid data from the four 260-ha areas located on the Chiefland Limestone Plain.

# Map Unit	Cadillac Variant	Candler	Hague Variant and Typic Hapludalfs
	Dominant soils and similar soils		
	-----------no. of observations------------		
12	184 *(68)	77 (28)	5 (4)
14	20 (17)	2 (2)	92 (81)

Map units 12 and 15 where combined based on GPR transects.
* Percent of named plus similar soils.

units 12 and 15 were combined based on earlier results). After summarizing the data from the four plots, the percentage of Cadillac Variant decreased from 90 percent for the initial plot to 68 percent for all 4 plots. Candler and similar soils increased from 10 percent to 28 percent for map unit 12. Arenic and Typic Hapludalfs increased from 50 to 81 percent with Grossarenic soils decreasing from 50 to 17 percent for map unit 14. Map unit 12 would now be a complex based on grid data. The grid data for the 4 plots, which covered over 1040 ha, were similar to the data values determined using GPR (Table 2-8). Even though 61 GPR transects were conducted throughout the CLP, the combined area investigated by the GPR was 2-ha.

Final Flex-Grid and Transect Procedure

On the basis of GPR interpretations, the final procedure combined the flex-grid mapping system and GPR transects. The flex-grid was used to delineate the map unit boundaries and the GPR was used to verify the map unit components. The grid interval varied according to soil complexity as determined by the initial GPR investigation. In areas where the depth to the Bt horizon was greater than 1 m, the flex-grid interval was approximately 200 m, but in areas where the depth to the Bt horizon was less than 1 m, the flex-grid interval varied from 30 to 100 m.

New soil series were proposed to replace the variants. Classification of the soils identified in the final survey

is given in Table 2-6. Brief field descriptions of each soil are presented in Table 2-7.

Sixty-one GPR transects were conducted across the CLP during the flex-grid mapping procedure. Transects were located within map units as randomly as possible. Landowner permission and radar accessibility were the major limiting factors in locating transects.

The radar images of diagnostic soil horizons were traced laterally on the GPR graphic profiles for each transect. The percent of each soil, as represented on the GPR graphic profile, could not be estimated by measuring it's length on the graphic profile due to the variations in the horizontal speed of the radar. Each observation point on the GPR profile, which was related to known points on the ground, was assigned a soil series name. For example, if the Bt horizon was within 1 m of the surface and limestone was > 1.0 m deep, Shadeville fine sand was noted for that observation point. Soils with similar interpretative characteristics were grouped for each transect (Soil Survey Staff, 1983). Similar and dissimilar soils were distinguished by drainage and depths to Bt horizons and limestone. Similar soils normally differed from named soils due to slight color or texture variations which were outside the range of the named soil series. The map units were thus defined based on the interpretative characteristics of the soil population (Edmonds et al.,

Table 2-6. Series and classification of soils used in the final descriptive legend for the Chiefland Limestone Plain.

Series	Family Classification
Candler	Hyperthermic, uncoated Typic Quartzipsamments
Shadeville *	Loamy, siliceous, thermic Arenic Hapludalfs
Jonesville	Loamy, siliceous, hyperthermic Arenic Hapludalfs
Levyville *	Fine-loamy, siliceous, thermic Arenic Hapludalfs
Otela *	Sandy, siliceous, thermic Arenic Hapludalfs +
Tavares	Hyperthermic, uncoated Typic Quartzipsamments
Seaboard *	Hyperthermic, uncoated Lithic Quartzipsamments

* These series have been proposed.
\+ Classification of soil would be Grossarenic if allowed by Soil Taxonomy (Soil Survey Staff, 1975).

Table 2-7. Abbreviated field descriptions of soils on the Chiefland Limestone Plain.

Horizon	Depth (cm)	Color (moist)	Texture	Structure+	Consistence+ (moist)
--------Otela--------					
Ap	0-20	10YR 4/2	fs	1fgr	vf
AE	20-54	10YR 5/3	fs	sgl	-
E1	54-81	10YR 8/3	fs	sgl	-
E2	81-127	10YR 8/1	fs	sgl	-
Bt1	127-155	10YR 6/6	fsl	2msbk	fr
Bt2	155-173	10YR 6/6	scl	2fsbk	fr
		*c2d 10YR 7/2			
2Cg	173-203	10YR 7/2	scl	massive	fr
--------Candler--------					
Ap	0-35	10YR 5/2	fs	sgl	-
E1	35-75	10YR 6/3	fs	sgl	-
E2	75-152	10YR 7/3	fs	sgl	-
E/Bt	152-200	10YR 8/2	fs (E)	sgl	-
		10YR 5/6	lfs (Bt)		
--------Tavares--------					
Ap	0-18	10YR 3/2	fs	sgl	-
C1	18-61	10YR 5/3	fs	sgl	-
C2	61-104	10YR 5/3	fs	sgl	-
		*c1d 10YR 5/8			
C3	104-147	10YR 6/3	fs	sgl	-
		*c2d 10YR 5/8			
C4	147-200	10YR 8/2	fs	sgl	-
		*f1d 10YR 6/6			
--------Jonesville--------					
Ap	0-13	10YR 5/1	fs	sgl	-
E1	13-35	10YR 6/2	fs	sgl	-
E2	35-68	10YR 7/1	fs	sgl	-
Bt	68-88	10YR 6/6	scl	1fsbk	fr
R		10YR 8/1	limestone		
--------Levyville--------					
Ap	0-18	10YR 3/3	fs	1fgr	vfr
E	18-43	10YR 6/6	s	sgl	-
Bt1	43-79	7.5YR 5/8	fsl	1msbk	fr
Bt2	79-112	10YR 5/8	fsl	1msbk	fr
C	112-203	10YR 6/4	fs	sgl	fr

Table 2-7--Continued.

Horizon	Depth (cm)	Color (moist)	Texture	Structure+	Consistence+ (moist)
----------Shadeville----------					
Ap	0-28	10YR 3/2	s	1fgr	vfr
E1	28-68	10YR 4/6	fs	sgl	-
E2	68-89	10YR 7/6	fs	sgl	-
Bt	89-152	7.5YR 5/8	fsl	2msbk	fr
2Cg	152-162	10YR 7/2	fsl	massive	fr
3R		10YR 8/1	-		
----------Seaboard----------					
Ap	0-18	10YR 4/2	fs	sgl	-
C	18-45	10YR 8/3	fs	sgl	-
2R		10YR 8/1	-		

+ 1=weak; 2=moderate; f=fine; m=medium; sgl=single grain loose; gr=granular; sbk=subangular blocky; vfr=very friable; fr=friable. Coded according to Appendix I, Soil Taxonomy (Soil Survey Staff, 1975).
* Mottles.

1982; Edmonds et al., 1985a, 1985b; Edmonds and Lentner, 1986) rather than strict adherence to taxonomic classification.

Intriplex Map Units

As the soil survey of the CLP progressed, complexes were found to be inadequate in describing soil and landscape patterns. Complexes inferred a certain knowledge about soil and landscape patterns. Variations in depths of Bt and R horizons were not predictable based on interpretation of the present landscape surface on the CLP. Therefore, to delineate map units as complexes would convey more knowledge about the soils than is presently known. Soil scientists should not only be concerned with the accuracy of soil boundaries, but also with the design and validity of the map units as measured against the standards established for nomenclature. The "intriplex" map unit was defined to more accurately convey a concept about soil and landscape patterns.

The result of the flex-grid survey and GPR procedure was the identification of four map unit intriplexes (Table 2-8) within the CLP. Representative GPR graphic profiles for the map unit intriplexes are given in Figs. 2-4 to 2-6.

A confidence level of 95% was used for the Otela-Candler, the Otela-Tavares, and the Shadeville-Otela-Levyville intriplexes. Confidence level for the Jonesville-Otela-Seaboard intriplex was at the 80% level. This latter

Table 2-8. Average composition of map units as determined by the ground-penetrating radar transect method.

Map Unit Name (intriplex)	Soil	Named ++ and Similar (%)	No. of * Transects	# C.I. (%)	# C.L. (%)	# C.V. (%)
Otela-Candler	Otela (Bt>1m)	57	21	97-84	95	16
	Candler (lamellae)	33				
Otela-Tavares	Otela (Bt>1m)	47	13	99-78	95	20
	Tavares (MWD) +	42				
Shadeville-Otela-Levyville	Shadeville (Bt<1m) (R>1.5m)	43	19	95-76	95	24
	Otela (Bt>1m)	26				
	Levyville (Bt<0.5m)	17				
Jonesville-Otela-Seaboard	Jonesville (Bt<1m) (R<1m)	38	8	88-76	80	15
	Otela (Bt>1m)	22				
	Seaboard (R<0.5m)	21				

++ "Dissimilar " soils make up the remaining percentage to 100.
+ Moderately well drained.
* Each transect had 10 equally spaced observation points.
# C.I. is confidence interval. C.L. is confidence level. C.V. is coefficient of variation.

intriplex only had 8 transects, which accounts, in part, for its lower confidence level.

Otela-Candler and Otela-Tavares intriplexes

The Otela-Candler intriplex, which is illustrated in Fig. 2-4, was estimated to be 57% Otela and similar soils and 33% Candler and similar soils. Twenty-one GPR transects were conducted in this unit. The confidence interval for the named plus similar soils was 84 to 97% (Table 2-8).

Otela-Tavares intriplex was similar to the Otela-Candler intriplex except that the Tavares soil is moderately-well drained. Candler soils are excessively drained. The Otela series plus similar soils were 47% of the mapped area and the Tavares series and similar soils were 42%. The named plus similar soils made up 78 to 99% of the Otela-Tavares map unit.

Generally, the observational density of the flex-grid for these map units was 1 grid intersect per 3-ha. The Otela-Tavares intriplex occurred between the 3.0 to 7.5 m elevation range while the Otela-Candler intriplex occurred from the 7.5 to 15 m range. The subsurface features of these soils were highly irregular but the topography of the surface was nearly level.

Shadeville-Otela-Levyville intriplex

Shadeville-Otela-Levyville intriplex was composed mostly of well-drained Hapludalfs which varied in depths to the Bt horizon and to limestone (Fig. 2-5). The Shadeville

Figure 2-4. Ground-penetrating radar graphic profile of the Otela-Candler intriplex map unit.

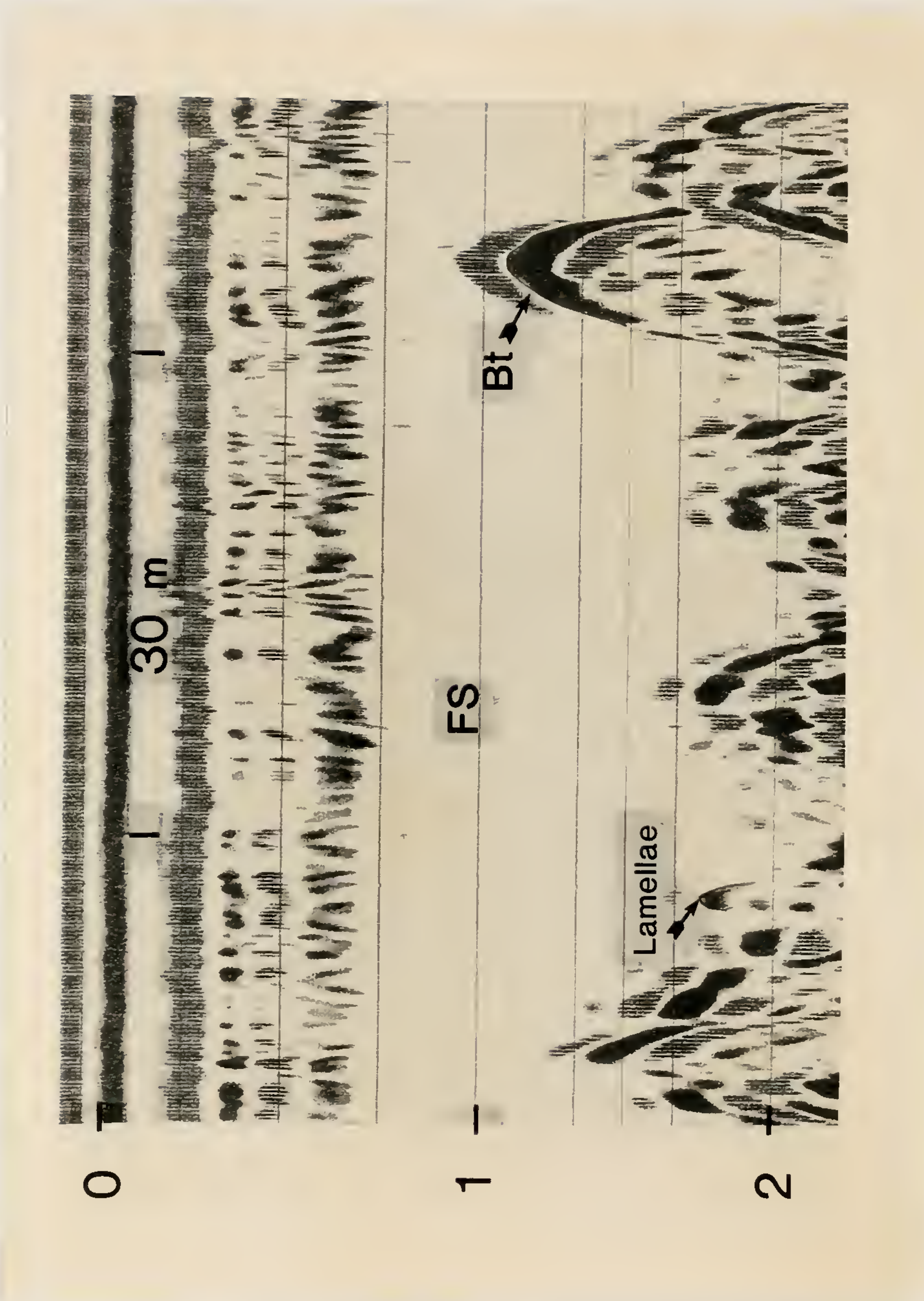
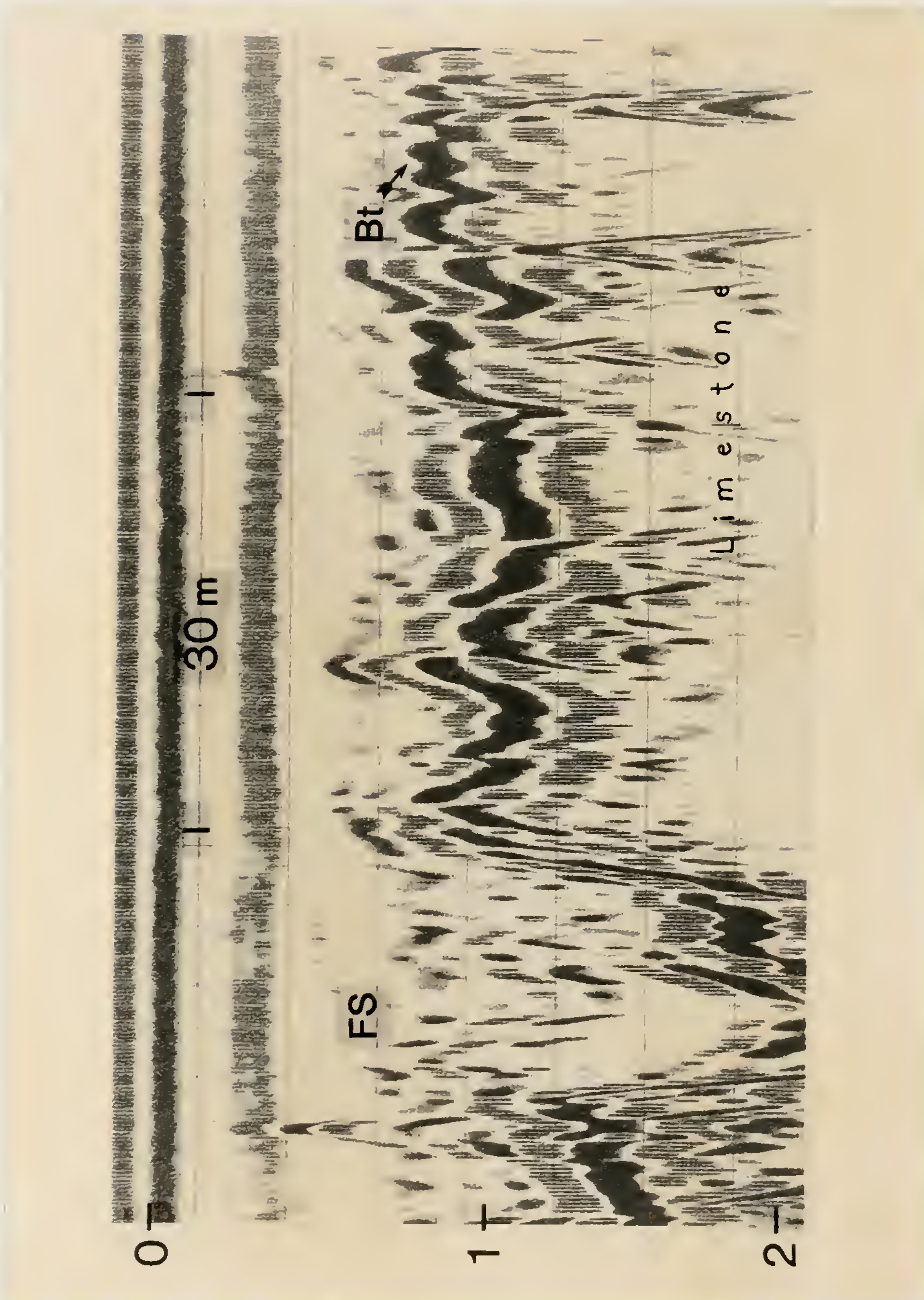

30 m
FS
Bt
Lamellae
0
1
2

Figure 2-5. Ground-penetrating radar graphic profile of the Shadeville-Otela-Levyville intriplex map unit.



0
1
2
30 m
FS
Bt
Limestone

series and similar soils made up 43% of this map unit. In Fig. 2-5, the area where the Bt horizon was greater than 1 m below the soil surface was identified as a collapsed feature and was mapped as the Otela series. The Otela series accounts for 26% of this map unit. The Levyville series and similar Typic Hapludalfs accounted for 17% of the unit. The flex-grid density within this unit was 1 to 3 grid intersects per ha. More grid intersects were needed to delineate the boundaries of map unit 14 than for the deeper sola map units.

In some areas, the Bt horizons were well developed and produced a broad, dark, band on the GPR profile (Fig. 2-5). However, the interfaces between the Bt and R horizons were not as easily distinguished due to the similar dielectric properties of the Bt horizon and the limestone. Limestone was normally detected by the presence of hyperbolic images on the radar graphic profiles. Generally, cavities are represented as hyperbolic images on GPR graphic profiles (Kuhns, 1982; Ballard, 1983). The cavities in Fig. 2-5, are adjacent to the word "limestone". Cavities in the limestone are normally filled with air and/or water. The dielectric properties of air and water contrast strongly with that of limestone (Ulriksen, 1982) and cause the radar waves to be reflected strongly.

Jonesville-Otela-Seaboard intriplex

The Jonesville-Otela-Seaboard intriplex consisted of dominantly moderately deep (R horizon < 1 m) and shallow (R horizon < 0.5 m) well-drained soils (Fig. 2-6). The Jonesville series and similar soils made up 38% of this unit. Ground-penetrating radar signals associated with the Seaboard series (R horizon <0.5 m) were in the central portion of Fig. 2-6. The large pinnacle of limestone, in the center of Fig. 2-6, has an irregular pitted surface which accounts for the intricate soil patterns in this map unit. The Otela soils are on the left side of the central limestone feature. The solution features on each side of the limestone pinnacle were believed to have formed along fracture planes in the limestone. These solution features were not well expressed at the surface. The subsurface variability of the Jonesville-Otela-Seaboard intriplex was easily observed where the soil cover had been removed exposing the underlying bedrock (Fig. 2-7). Thin, discontinuous Bt horizons mantled the limestone in some areas. The Seaboard soils and similar soils occurred where the Bt horizon was absent. The flex-grid density for this map unit varied from 1 to 3 observations per ha.

Conclusions

A survey method for mapping soils on karst using flex-grid techniques and GPR proved to be an effective

Figure 2-6. Ground-penetrating radar graphic profile of the Jonesville-Otela-Seaboard intriplex map unit.

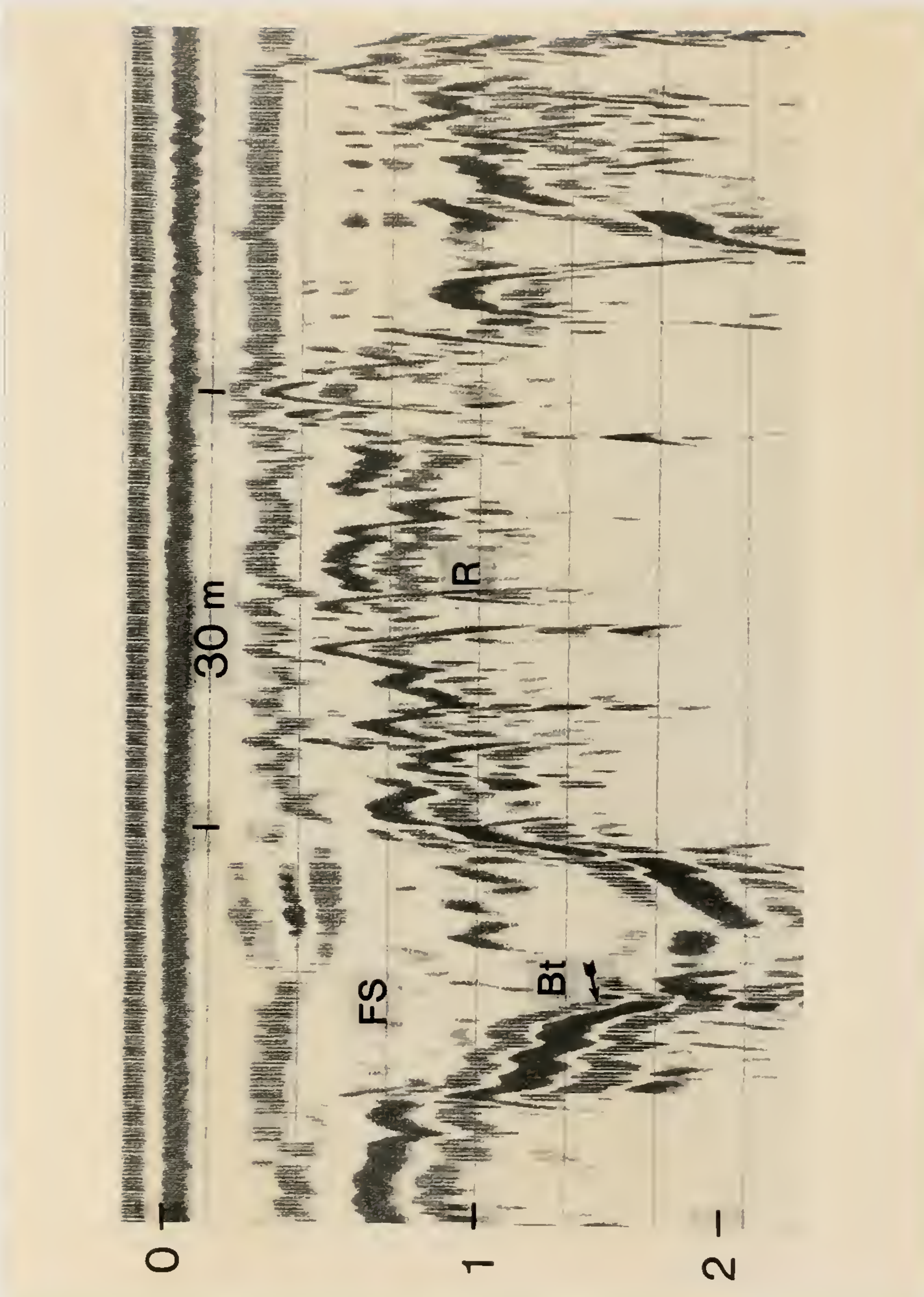

0
1
2
30 m
FS
R
Bt

Figure 2-7. Exposed limestone bedrock within the Jonesville-Otela-Seaboard intriplex map unit illustrating the subsurface variability of the limestone.

alternative where soils and landscapes were independent of each other. In the karst areas of west-central Florida, where subsurface soil features often change rapidly and dramatically over short horizontal distances with no surface expression, the GPR was ideal for studying the magnitude, extent, and variability of this change. The radar provided a continuous subsurface profile where landscape features could not be used to separate soils. The GPR also allowed a larger sample of the soil population to be examined, which increases the accuracy of the map unit descriptions in the soil survey report. The data presented in Table 2-8 will be published in the "Soil Survey Report of Levy County, Florida".

The intriplex map unit was also introduced as an alternative to the complex map unit in areas where soils and landscapes appeared to occur randomly. The intriplex map unit was proposed to more accurately reflect the state of soils and landscapes on karst in west-central Florida.

CHAPTER 3
RADAR-GRID CATEGORIES OF SUBSURFACE FEATURES ON THE CHIEFLAND LIMESTONE PLAIN

Introduction

The soils and landscapes of the CLP appeared to vary independently at a scale of 1:24000 (Chapter 2). The soils on the CLP have been strongly influenced by sea level fluctuations and karst processes. Identification of subsurface features on the CLP and mapping their lateral and vertical variability by normal soil survey procedures were not effective.

The ground-penetrating radar (GPR) has been used for determining soil components in map units (Johnson et al., 1980; Doolittle, 1982; Collins et al., 1986; Schellentrager et al., 1988), determining soil microvariability (Collins and Doolittle, 1987; Collins et al., 1989; Rebertus et al., 1989), determining soil thickness (Shih and Doolittle, 1984; Olson and Doolittle, 1985; Collins et al., 1986), and detection of subsurface cavities and geologic materials (Kuhns, 1982; Ballard, 1983; Hearns, 1987). Asmussen et al. (1986) used the GPR to study the subsurface dimensions of the Hawthorn Formation and to develop radar signatures for dominant Coastal Plain soils in south Georgia.

The objectives of this chapter were to (a) develop relationships between the graphic GPR profiles and the soils of the CLP, and (b) to qualify the spatial characteristics of the soils identified using GPR.

Materials and Methods

Location and Selection of Study Area

The 4-ha study area shown in Fig. 3-1a and 3-1b, referred to as the Quincey plot (QP), was located on the CLP, in Levy County (Fig. 1-1). The QP was selected after analysis of information obtained from the 61 GPR transects that had been conducted on the CLP (Chapter 2). Also, field observations indicated that the QP was composed of soils and karst features that were representative of the CLP. Elevations on the QP range from 12 to 17 m above mean sea level.

GPR System

The GPR is an impulse radar system designed for shallow subsurface investigations. The GPR generates an electromagnetic wavefront which is propagated into the ground through an antenna that is electromagnetically coupled to the ground. The generated pulses are composed of a number of frequencies that are distributed around the central frequency of the antenna (Olson and Doolittle, 1985). When a pulse strikes an interface of differing electrical properties, a part of the pulse's energy is

Figure 3-1. Ground views of the Quincey Plot.
a) Looking from the southwest to the northeast from observation station 0,0. Wooden stakes indicate locations of each observation station (interval between stakes was 10 m).
b) Looking from the east to the west-northwest from observation station 18,7.

a.

b.

reflected back to the antenna. The reflected pulses are processed and displayed on a graphic recorder in various shades of gray. Strong reflections are displayed by the graphic recorder as black with intermediate reflections recorded in shades of gray. Radar pulses that are attenuated and not returned to the antenna are recorded as white.

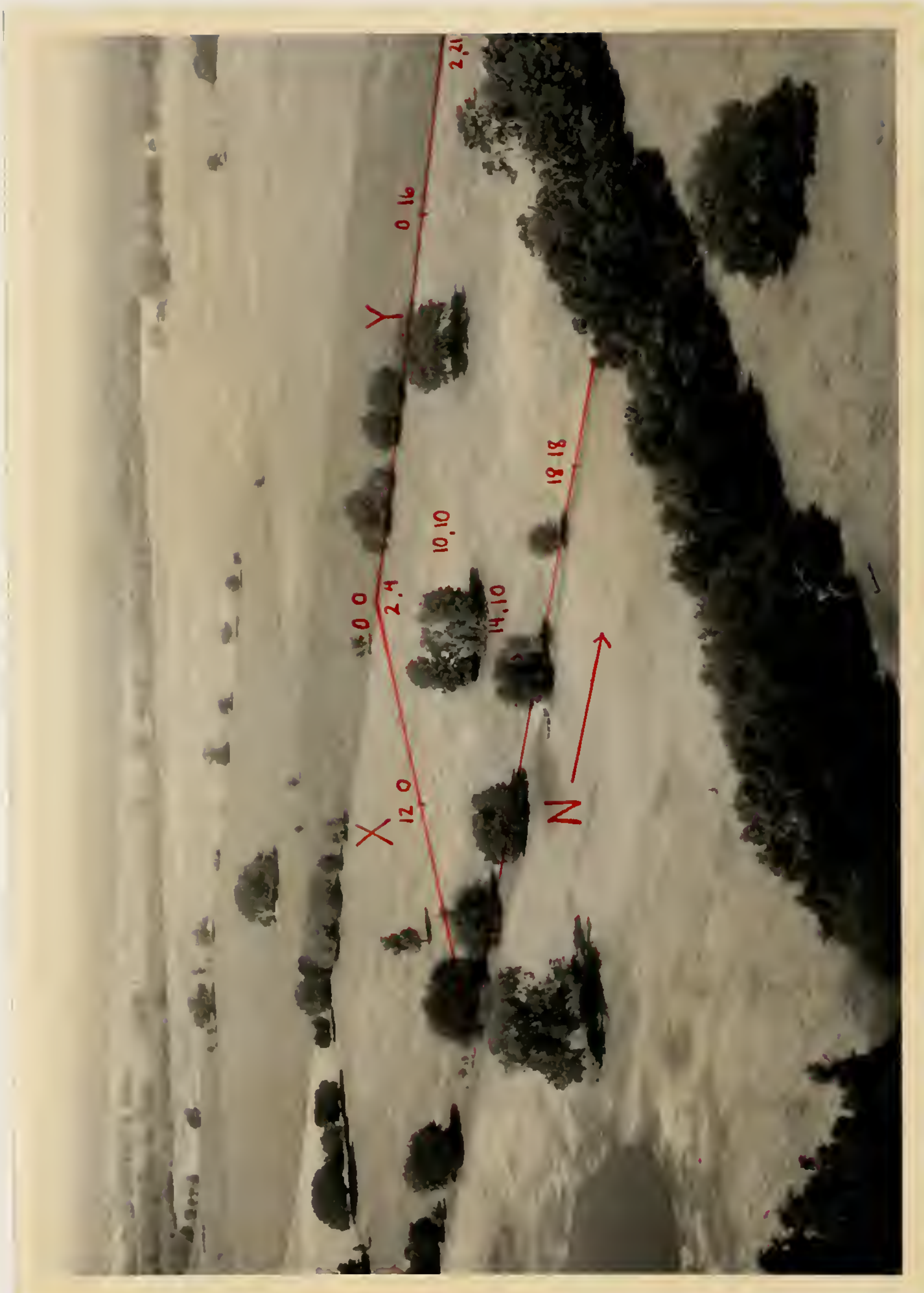
The probing depth of the GPR is largely determined by the electrical properties of the soil. Soil properties that influence the electrical conductance of the soil are water content, concentration of salts in solution, adsorbed ions on clay particles, and amount and type of clays (Johnson et al., 1980; Shih and Doolittle, 1984; and Olson and Doolittle, 1985).

The GPR system used was the Subsurface Interface Radar (SIR) System-8 (The trade name has been used to provide specific information. Its mention does not constitute endorsement). A 120-MHz antenna was used at a speed of 4.0 to 5.5 km/hr. The scanning time of the GPR was 70 ns, with a scanning rate of 25.6 scans/s.

<u>Grid Survey and GPR Transects</u>

A rectangular grid, using 10 m spacings, was established on the QP. The grid was 230 m in the north-south direction and 190 m in the east-west direction (Fig. 3-2). Surface elevations were recorded at each grid

Figure 3-2. Aerial view of the Quincey Plot from the northeast. Locations of the sampled soils are shown using grid coordinates.



Y
0.16
0.0
2.4
10.10
14.10
18.18
X
12.0
N

interval (observation stations) using a transit. Elevations were tied to a USGS benchmark located near the QP.

The first transect line (0,0 to 0,22) was transected north to south using a 120-MHz, 300-MHz and 500-MHz antenna. This was done in order to determine which antenna or antennae would be best utilized for the investigation. The 120-MHz antenna was selected due to better resolution between soil depths of 34 and 285 cm.

Nineteen GPR transects were conducted in a north-south direction on the QP. Thirty-five soil borings were made in order to collect field notes (i.e., diagnostic horizons, colors, textures, drainage and depth to limestone) needed to scale the radar imagery. Soil data were collected to a depth of 2 m or to limestone, whichever was shallower. The GPR graphic profiles were scaled by measuring the distance from the ground surface pulse to the first interface. The GPR data were regressed against measured depths at 29 of the 35 observation stations (R-squared=0.94). Six of the observation stations were excluded due to poor resolution of the 120-MHz antenna at shallow depths (0.5 m) or lack of depth measurements below 2 m. The minimum resolution of the 120-MHz antenna was 34 cm. The 34 cm depth was in agreement with the findings of Rebertus et al. (1989), who reported that strong surface and near surface reflections made interpretations of subsurface interfaces less accurate

within depths of 25 to 35 cm than at deeper depths using the 120-MHz antenna.

Temporal effects on GPR graphic profiles are not known. Therefore, the results reported here are relative to the field conditions the day the transects were conducted. The GPR transects for the QP were conducted during a period of drought to minimized the effects of moisture on the GPR graphic profiles. Perched or apparent water tables produce strong interfaces on the graphic profiles and, therefore, confound the process of horizon identification.

Definition of Radar Class and Radar-Grid Category

Radar class

A radar class (RC) is defined as "a unique GPR graphic profile that is representative of a specific arrangement of soil horizons or geologic strata". A radar class represents a subdivision of a GPR graphical profile into its most basic recognizable graphic component.

Radar-grid category

A radar-grid category (RGC) is defined as "a collection of similar RCs that have spatial distribution and are representative of a defined soil component or components". Soil components were defined in Chapter 2. A RGC is a grouping of RCs into a useful and meaning spatial arrangement. The characteristics of a RGC are defined by the graphic properties of the RC and the range of

characteristics that define the basic soil component or components.

Selection of Representative Pedons

The 19 GPR graphic profiles were carefully studied and seven RCs were chosen as unique and representative of all radar images in the QP. The seven RCs represented seven different graphical image profiles. After the RCs were identified and defined, soils were selected and sampled within each RC to establish qualitative relationships between the graphical radar profiles of each RC and soil characteristics.

Laboratory Analysis

The seven selected pedons were described and sampled by horizon. Bulk soil samples were air dried and sieved to remove particles larger than 2 mm. A subsample was ground in a ball mill to pass a 250-um sieve. The subsamples were used to determine total phosphorus (TP) contents.

Particle-size analysis was performed using the pipette method (Day, 1965). Total phosphorus content was determined using the alkaline-oxidation method developed by Dick and Tabatabai (1977) as modified by Walter (Collins, 1977).

Cation exchange capacity (CEC) was calculated by summation of the extractable bases (Na, K, Mg and Ca), using as an extractant 1 M NH_4OAc pH 7.0 (Soil Survey Staff, 1984); and extractable acidity, using 0.25 M $BaCl_2$ TEA pH

8.2 (Soil Survey Staff, 1984). Electrical conductivity (EC) measurements were made using a 1:1 ratio of soil to water.

The A and E horizon samples were treated with NaOCl to remove organic matter in preparation for mineralogical analysis. Samples were pretreated with Na citrate-dithionate-bicarbonate to remove oxide coatings (Mehra and Jackson, 1960). Organic matter and iron were removed due to the confounding effects of these cementing agents on dispersion and the proper orientation of clay on the ceramic tile.

Sand was separated by wet sieving. Silt and clay were dispersed by adjustment of the suspension pH to 10 with Na_2CO_3 and then separated by centrifugation and decantation.

Oriented mounts of clay fractions were prepared by depositing approximately 250 mg from the suspension onto a ceramic tile under suction, saturating with Mg or K, washing free of salts using distilled water, and adding glycerol to the Mg-saturated samples.

Clay minerals were identified from x-ray diffraction (XRD) patterns of Mg-saturated clay (air dry and 110^{o}C) and air dry, 100^{o}, 300^{o} and 550^{o}C heated, K-saturated clay. X-ray diffraction analysis was conducted using a Nicolet I2 computer-controlled system. Samples were scanned at 2^{o} 2θ per minute using CuK-alpha radiation. Minerals were identified from XRD patterns using differentiating criteria outlined by Whittig and Allardice (1986).

Statistical Methods

The UNIVARIATE procedure (SAS Institute, 1988) was used to calculate the means (X), medians (Md), modes (Mo), coefficients of variation (CV), and standard error of the mean (SE). The NORMAL option was used to compute the probabilities (p-values) associated with the Shapiro-Wilk W-statistic for testing for normal distributions.

The nearest-neighbor analysis method developed by Clark and Evans (1954) was used to determine the pattern characteristics of the soils in the QP. In this analysis, the observed mean nearest-neighbor distance for a set of points was compared to the theoretical mean distance for a (a) clustered, (b) random, and (c) dispersed arrangement. The expected mean nearest-neighbor distance for a random arrangement of points is given by

$$Dran=1/(2*p) \qquad [1]$$

where Dran is the expected mean nearest-neighbor distance for a random arrangement and p is the density of points per unit area (number of observations divided by the area).

The expected mean nearest-neighbor distance for a dispersed arrangement of points is given by

$$Ddis=1.07/p \qquad [2]$$

where Ddis is the expected mean nearest-neighbor distance for a dispersed arrangement. The calculation of Ddis is based on a hexagonal arrangement of points, which gives the maximum distance that could exist between points.

The observed mean nearest-neighbor distance for an arrangement of points is given by

$$Dobs=d/n \qquad [3]$$

where Dobs is the observed mean nearest-neighbor distance, d is the sum of the measured nearest-neighbor distances for the observed points, and n is the number of points.

The test statistic or nearest-neighbor index is given by

$$R=Dobs/Dran \qquad [4]$$

where R is the nearest-neighbor index. The value of R can be compared with standard table values (Ebdon, 1983) to test its significance. The value of R is equal to 0 if the arrangement of points is clustered. If the arrangement of points is random then the value of R is equal to 1. For a completely dispersed arrangement of points, the value of R is equal to 2.15.

The hypothesis tested for the QP was

Ho: The observed arrangement is the result of points being located at random in the QP.
Ha: If R < tested R then points are clustered.
If R > tested R then points are dispersed.

Relationships between the soils and landscapes on the CLP were not apparent at the scale of 1:24000 (Chapter 2). The nearest-neighbor analysis was intended to test the hypothesis that the soils in the QP occurred at random and exhibited no apparent pattern. Burrough (1983) suggested that systematic and random variations were entirely scale

dependent because increasing the scale of observation almost always reveals structure in the random variations.

Computer-Generated Maps and Diagrams

Computer-generated contour maps and surface-net diagrams were created using the SURFER software programs. The Inverse Distance method with a weighting power of 2 was used to create the surface-net diagrams.

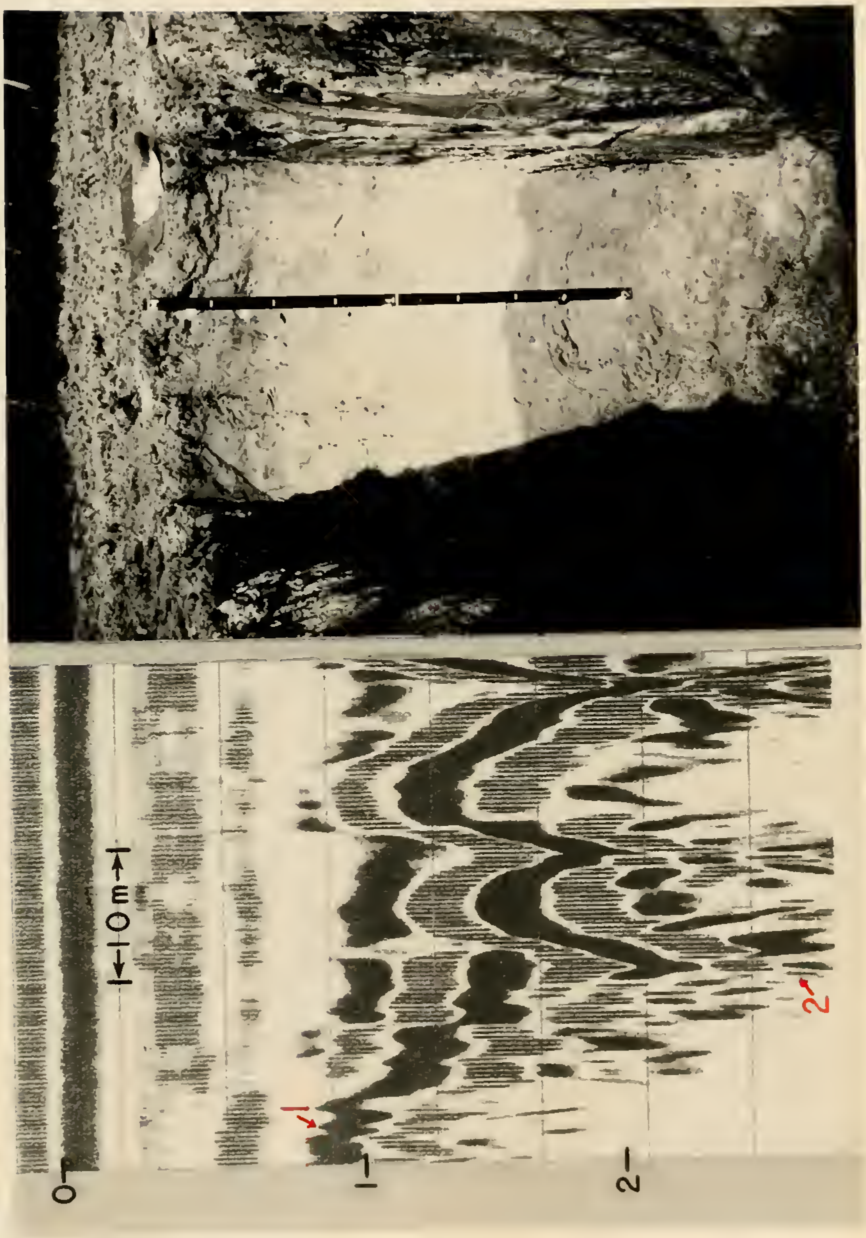
Results and Discussions

Radar Classes

The seven RCs identified from the GPR graphic profiles will be identified by letters. Radar class "A" was identified by the occurrence of two radar interfaces below 1 m. The first radar interface was a continuous broad, black band and the second a discontinuous grayish-black band (Fig. 3-3a). The wide gray band below the surface pulse was smooth and continuous which indicated that interference was not occurring between the surface pulse and the first subsurface interface. This means that the distance between the soil surface and the first soil horizon was greater than one-half of the wavelength of electromagnetic pulse.

Radar class "B" was characterized by a broad, continuous black band above 1 m (Fig. 3-4a). The hyperbolic reflections below 1 m and to the right of center were considered to be associated with the presence of limestone. Cavities or cracks in the limestone produce characteristic

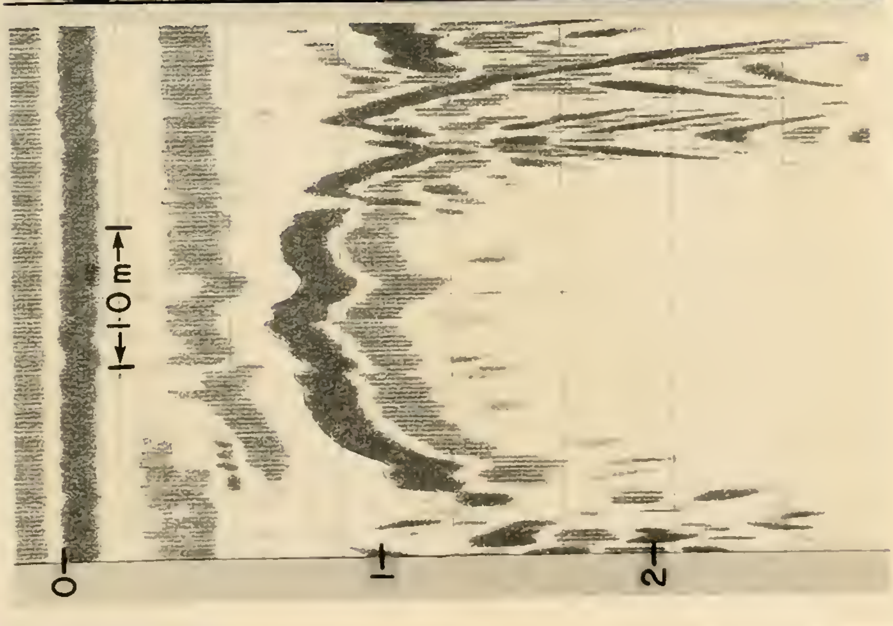
Figure 3-3. Graphic-radar profile and Otela soil profile at observation station 0,16 in the Quincey plot.
a) Graphic-radar profile for radar class A. 1=first-radar interface and 2=second-radar interface;
b) Sampled pedon 0,16 representing the Otela soils.



a.

b.

Figure 3-4. Graphic-radar profile and Shadeville soil profile at observation station 2,4 in the Quincey plot.
a) Graphic-radar profile for radar class B;
b) Sampled pedon 2,4 representing the Shadeville soils.



a.

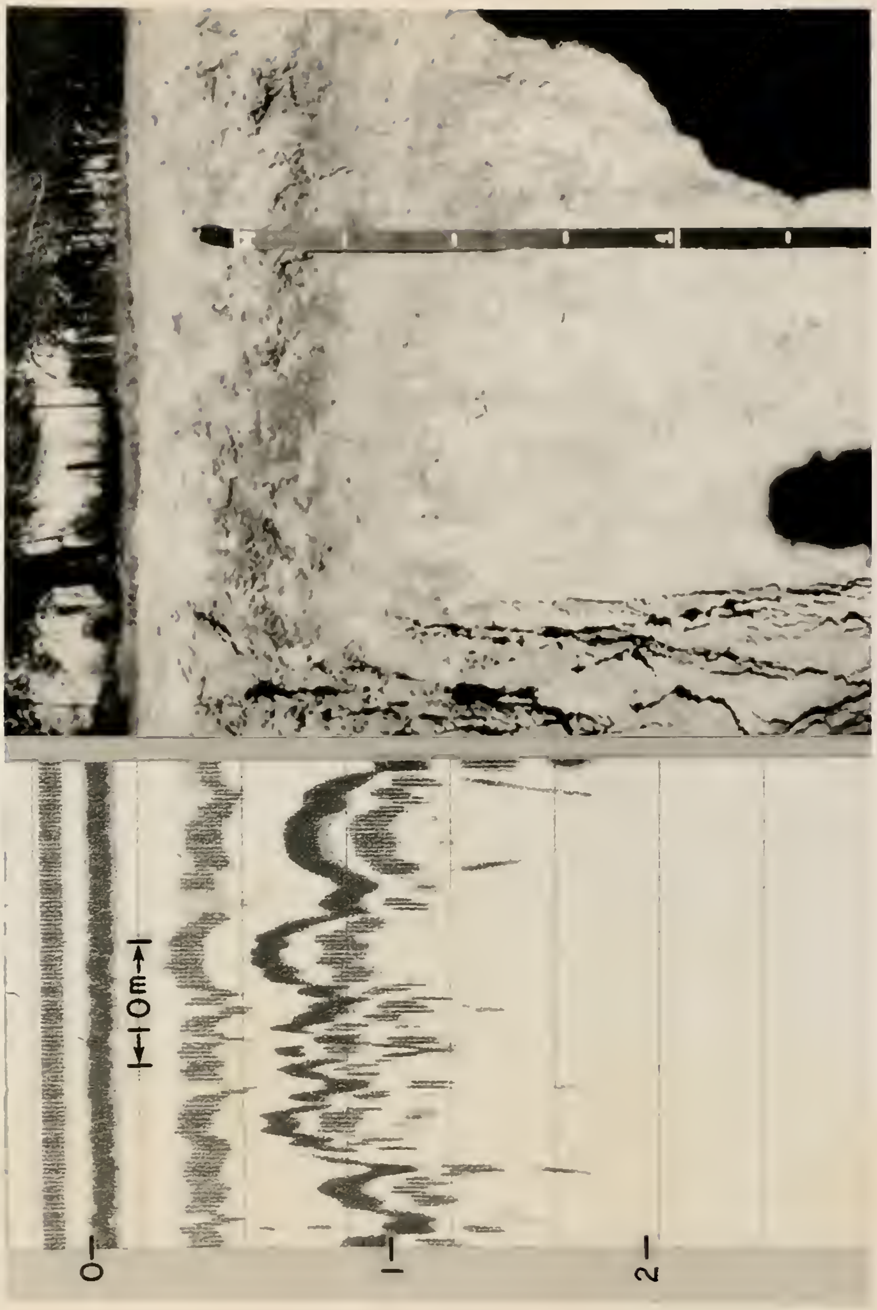
b.

hyperbolic signals on the graphic radar profiles (Kuhns, 1982 and Ballard, 1983). The hyperbolic signals were due to the difference in dielectric properties of the air and water in the cracks of the limestone and also the limestone itself. However, Beck and Wilson (1988) suggested that a majority of the hyperbolic interfaces produced by the GPR were due to the geometry of the subsurface karst interfaces and not the presence of cavities. Ground-truthing is necessary to determine if the hyperbolic interfaces represent cavities or complex irregular subsurface geometry.

Radar classes "C" and "D" were very similar in appearance, in that both had an irregular, thin, black band above 30 cm. The gray bands below the surface pulses in RCs "C" and "D", were irregular and discontinuous which denoted that the subsurface interfaces were close to the soil surface (Figs. 3-5a and 3-6a). The GPR signals were rapidly dissipated below depths of 1 m in both RC's "C" and "D", i.e., the lack of interface bands below this depth. Class "C" was differentiated from "D" by the lack of weak hyperbolic point reflections below the first interface.

Radar class "E" had multiple discontinuous black and grayish black bands below 1 m (Fig. 3-7a). The predominate feature for RC "F" was the lack of graphical interfaces and the downward dipping of the adjacent graphical interfaces (Fig. 3-8a). This graphical profile was chosen because it

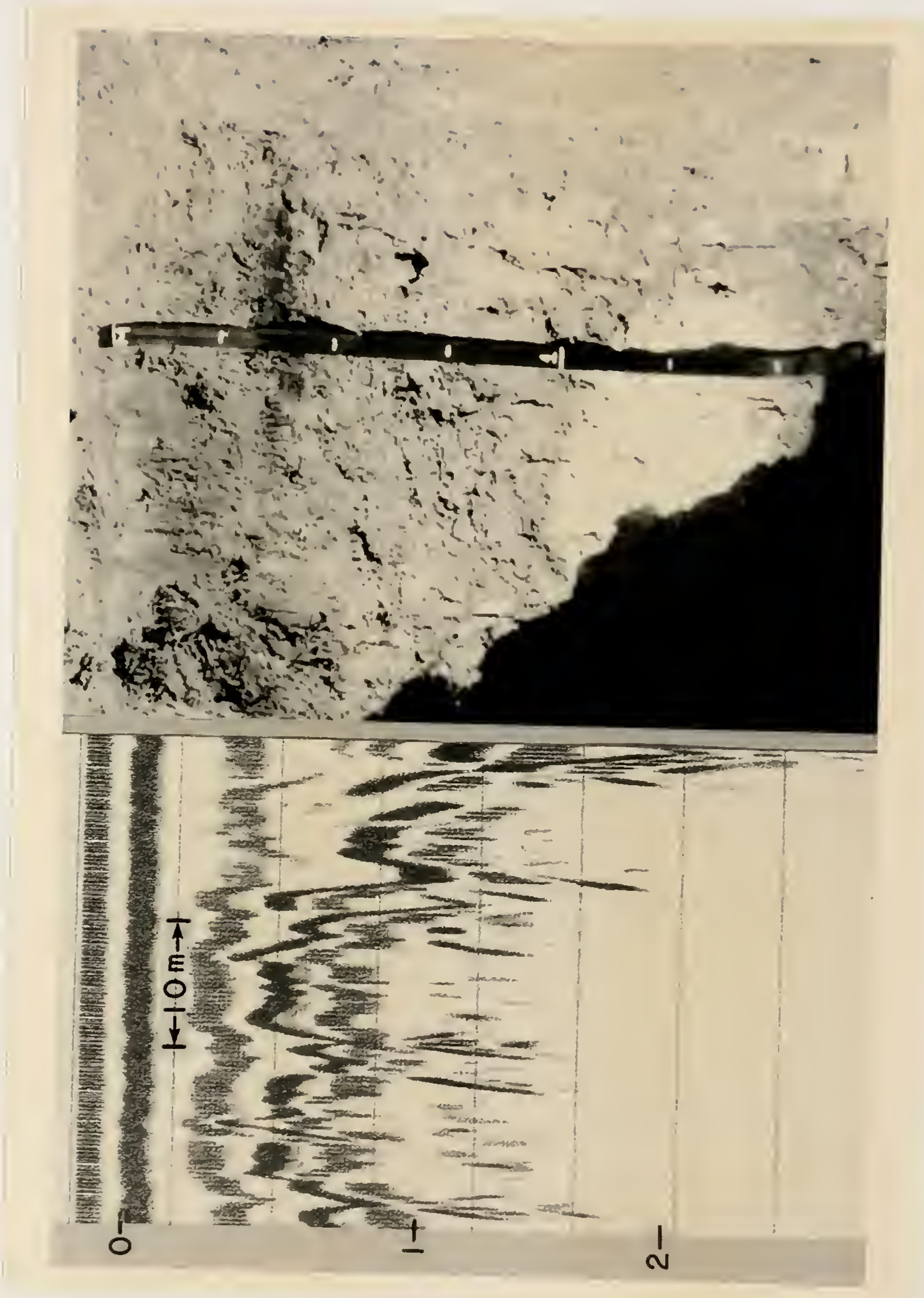
Figure 3-5. Graphic-radar profile and Pedro soil profile at observation station 2,21 in the Quincey plot.
a) Graphic-radar profile for radar class C;
b) Sampled pedon 2,21 representing the Pedro soils.



b.

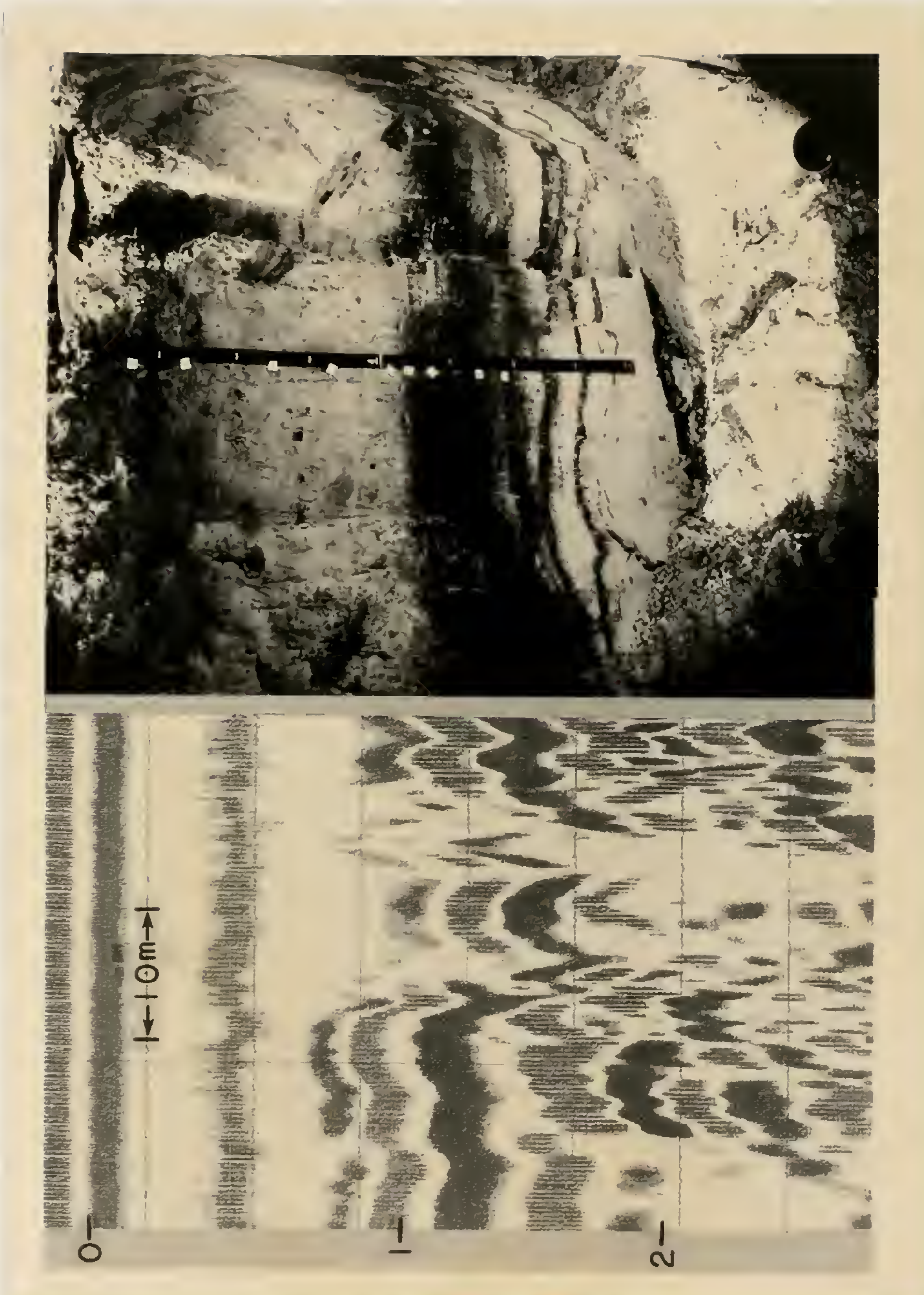
a.

Figure 3-6. Graphic-radar profile and Bushnell soil profile at observation station 10,10 in the Quincey plot.
a) Graphic-radar profile for radar class D;
b) Sampled pedon 10,10 representing the Bushnell soils.



a. b.

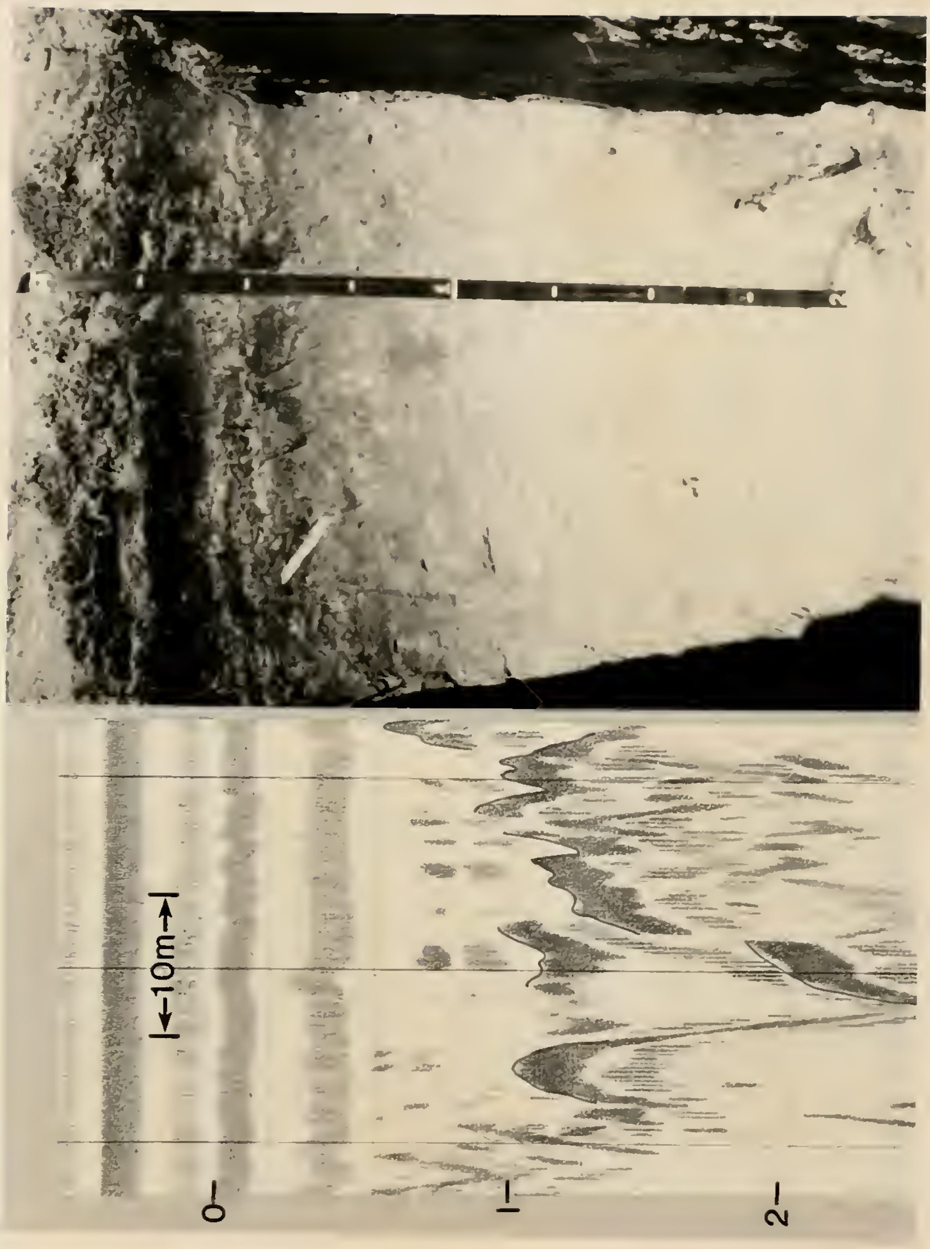
Figure 3-7. Graphic-radar profile and pedon 12,0 profile at observation station 12,0 in the Quincey plot.
a) Graphic-radar profile for radar class E;
b) Sampled pedon 12,0 representing pedon 12,0 soils.



a.

b.

Figure 3-8. Graphic-radar profile and pedon 14,10 profile at observation station 14,10 in the Quincey plot.
a) Graphic-radar profile for radar class F;
b) Sampled pedon 14,10 representing pedon 14,10 soils.



a.

b.

represented a unique segment of the QP landscape; the bottom of the sinkhole shown in Fig. 3-1b.

Radar class "G" also exhibited a lack of continuous graphical interfaces but did have point interfaces below 1 m (Fig. 3-9a). Point interfaces in this text refer to subsurface interfaces that are not continuous, i.e., lamella.

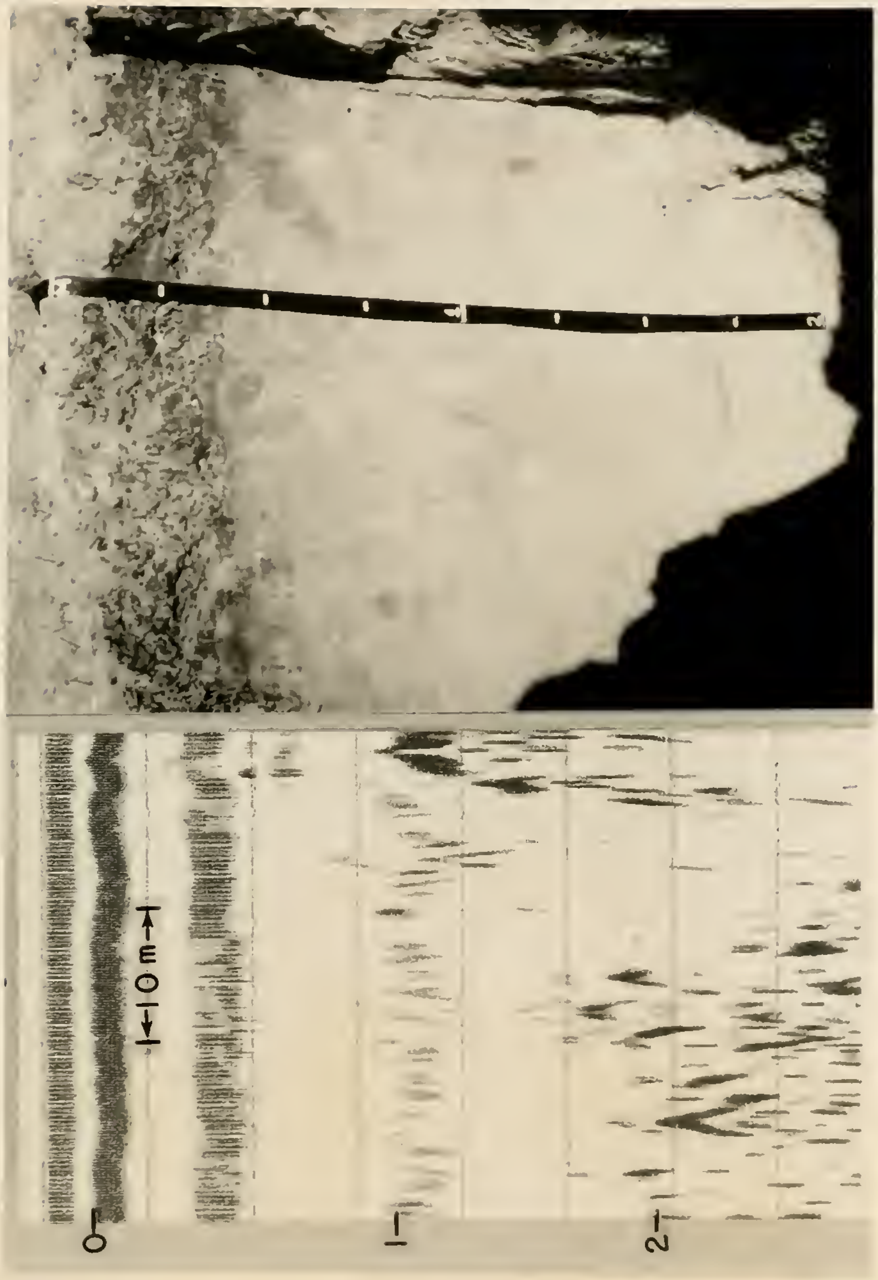
Radar Classes and Soil Characteristics

After the RCs were identified and defined, soils were selected and sampled for each RC to establish qualitative relationships between the graphical radar profiles of each RC and soil characteristics. Seven different soils are represented by the 7 RCs on 5 landscape positions.

Locations of the soils selected along with a contour map of surface elevation are presented in Fig. 3-10. Radar classes and grid coordinates of the sampled pedons are given in Table 3-1. The sampled soils are identified by grid coordinates. Abbreviated pedon descriptions are presented in Table 3-2.

Pedons 0,16, 2,21, and 12,0 all occurred on nearly level areas of the QP (Fig. 3-10). Pedon 2,4 was located on the sideslope of a small sinkhole. Pedon 14,10 was located in the bottom of a large sinkhole and pedon 10,10 was located on the shoulder slope of the same sinkhole. Pedon 18,18 occupied a summit position. Based on the conceptual soil-landscape model presented in Chapter 2 (Fig. 2-1),

Figure 3-9. Graphic-radar profile and Candler soil profile at observation station 18,18 in the Quincey plot.
a) Graphic-radar profile for radar class G;
b) Sampled profile 18,18 representing the Candler soils.



a. b.

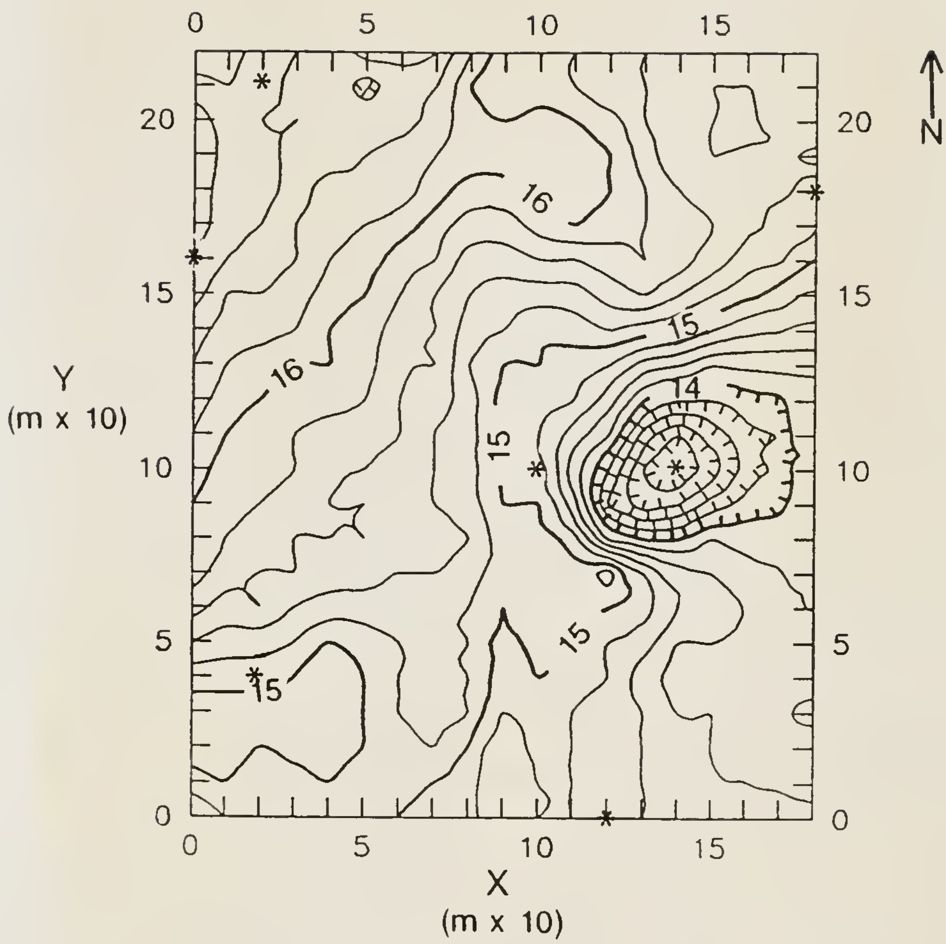


Figure 3-10. Computer-generated contour map of surface elevations and locations of sampled soils for the Quincey plot (contour interval, 0.2 m).

Table 3-1. Radar classes, pedon grid coordinates, and elevations of representative pedons at the Quincey plot.

Radar Class	Pedon Grid Coordinate (X,Y)	Elevation (m)
A	0,16	16.5
B	2,4	14.9
C	2,21	16.4
D	10,10	14.6
E	12,0	14.5
F	14,10	12.8
G	18,18	15.9

Table 3-2. Abbreviated field descriptions of representative soils at the Quincey plot.

Horizon	Depth (cm)	Color (moist)	Texture	*Boundary	*Structure
		Pedon 0,16			
Ap1	0-18	10YR 4/3	fs	cl/sm	1fgr
Ap2	18-36	10YR 3/1	fs	cl/sm	1mgr
AE	36-59	10YR 5/2	fs	cl/sm	1mgr
E1	59-88	10YR 7/3	fs	cl/sm	1mgr
E2	88-119	10YR 7/3	fs	cl/sm	1mgr
E3	119-138	10YR 8/1	fs	ab/wy	1mgr
Bt1	138-153	10YR 6/4	scl	cl/ir	2msbk
Bt2	153-193	10YR 6/4	scl	cl/wy	2msbk
Bt3	193-200+	10YR 6/6	sc	-	2msbk
		Pedon 2,4			
Ap1	0-16	10YR 4/1	fs	ab/ir	1mgr
Ap2	16-28	10YR 4/1	fs	ab/wy	1mgr
E1	28-51	10YR 6/2	fs	cl/sm	1mgr
E2	51-74	10YR 7/3	fs	ab/sm	1mgr
Bt1	74-112	10YR 5/3	fsl	ab/wy	2msbk
Bt2	112-145	10YR 5/3	fsl	ab/wy	2msbk
2Bt3	145-183	2.5YR 6/2	sc	gr/wy	2csbk
2Bt4	183-194	2.5YR 5/2	c	ab/wy	2csbk
3R	194+	-	-	-	-
		Pedon 2,21			
Ap	0-18	10YR 4/1	fs	ab/sm	1mgr
E	18-38	10YR 7/4	fs	cl/wy	sgl
Bt	38-50	10YR 6/6	scl	cl/ir	2msbk
2C	50-200+	10YR 8/2	sc	-	-
		Pedon 10,10			
Ap1	0-19	10YR 4/1	fs	gr/sm	1fgr
Ap2	19-34	10YR 4/1	fs	ab/wy	1msbk
2Bt	34-96	10YR 6/6	c	ab/ir	2msbk
3Cr	96-126	N 8/0	-	-	-
3R	126+	N 8/0	-	-	-

Table 3-2--continued.

Horizon	Depth (cm)	Color (moist)	Texture	*Boundary	*Structure
		Pedon 12,0			
Ap1	0-18	10YR 3/1	fs	gr/wy	2mgr
Ap2	18-37	10YR 3/2	fs	ab/sm	1msbk
C1	37-64	10YR 6/2	fs	di/wy	1fsbk
C2	64-85	10YR 6/2	fs	gr/sm	1fsbk
C3	85-106	10YR 7/1	fs	gr/sm	1fsbk
C4/Ab	106-112	(C4) 10YR 7/3	fs	ab/sm	1msbk
		(Ab) 10YR 4/3			
Ab1	112-119	10YR 3/3	sl	gr/sm	2msbk
Ab2	119-137	10YR 3/2	sl	gr/wy	2msbk
C'1	137-149	10YR 3/2	fs	gr/wy	1fsbk
		10YR 7/2			
C'2	149-156	10YR 4/2	fs	gr/wy	1fsbk
C'3	156-200+	10YR 8/1	fs	-	sgl
		Pedon 14,10			
Ap1	0-19	10YR 2/1	fs	cl/sm	1fgr
Ap2	19-37	10YR 2/1	fs	cl/sm	1fsbk
A	37-62	10YR 3/1	fs	gr/wy	1pl
Ab	62-104	10YR 5/2	fs	gr/wy	1fsbk
Eb	104-146	10YR 7/2	fs	gr/wy	sgl
Eb/Btb	146-200+	(E) 10YR 8/1	fs	-	sgl
		10YR 6/2	lfs	-	ma
		Pedon 18,18			
Ap1	0-29	10YR 4/2	fs	cl/wy	1fgr
Ap2	29-37	10YR 3/1	fs	ab/sm	1fgr
AE	37-72	10YR 5/3	fs	gr/wy	1fgr
E1	72-122	10YR 7/4	fs	gr/wy	1msbk
E2	122-182	10YR 8/2	fs	gr/wy	sgl
E/Bt	182-200+	(E) 10YR 8/2	fs	-	sgl
		10YR 6/4	lfs	-	ma

* ab=abrupt; cl=clear; gr=gradual; di=diffuse; sm=smooth; wy=wavy; ir=irregular; 1=weak; 2=moderate; f=fine; m=medium; c=coarse; sgl=single grain loose; ma=massive; gr=granular; sbk=subangular blocky; pl=platy. Coded according to Appendix I, Soil Taxonomy (Soil Survey Staff, 1975).

pedons 18,18 and 14,10 would be Typic Quartzipsamments; pedons 2,4 and 10,10 would be Lithic, Typic or Arenic Hapludalfs and pedons 0,16, 2,21 and 12,0 would be Arenic Hapludalfs with Bt horizons greater than 1 m.

The textures of the A and E horizons of all pedons are fine sand and the textures of the Bt horizons range from very fine sandy loam to clay. A summary of clay content, TP content, CEC, and EC for the seven soils is given in Table 3-3.

The clay mineralogy of the fine sand A, E, and C horizons was dominantly hydroxy-interlayered vermiculite (HIV), kaolinite, and quartz with trace amounts of smectites in some A horizons. The clay mineralogy of the upper Bt horizons, that were low in TP (< 1000 ug/g), were dominantly kaolinite, HIV, and quartz. The lower, more clayey Bt horizons were high in TP (>10,000 ug/g), and the clay mineralogy were dominantly kaolinite, apatite, crandallite, and smectite. Examples of the mineralogy of the coarse clay fraction is presented by horizon in Figs. 3-11 and 3-12, for pedons 0,16 and 2,21.

<u>Pedon 0,16</u>

Pedon 0,16 was identified as the Otela series (sandy, siliceous, thermic Arenic Hapludalfs) Fig. 3-3b. The Otela soil is the dominant soil on the CLP (Chapter 2, Table 2-8). The RC for pedon 0,16 is presented in Fig. 3-3a. The first graphic radar interface was between the E3 and Bt1 horizons.

Table 3-3. Summary of selected physical and chemical properties of representative soils in the Quincey Plot.

Horizon	Depth (cm)	Clay (%)	EC* (dS/m)	TP (ug/g)	CEC (cmol/kg soil)
		Pedon 0,16			
Ap1	0-18	1.7	0.03	378	6.5
Ap2	18-36	1.7	0.02	447	5.8
AE	36-59	1.6	0.01	383	4.0
E1	59-88	1.5	0.01	308	3.2
E2	88-119	1.4	0.01	221	3.1
Bt1	138-153	16.0	0.02	455	8.2
Bt2	153-193	15.6	0.02	398	8.3
Bt3	193-200+	33.5	0.01	10440	17.5
		Pedon 2,4			
Ap1	0-16	1.4	0.03	345	5.7
Ap2	16-28	3.1	0.03	335	5.8
E1	28-51	2.5	0.01	319	7.5
E2	51-74	2.2	0.01	192	3.6
Bt1	74-112	17.6	0.01	556	7.8
Bt2	112-145	18.0	0.02	520	6.5
2Bt3	145-183	30.0	0.02	12395	18.5
2Bt4	183-194	50.3	0.09	17856	38.1
		Pedon 2,21			
Ap	0-18	3.0	0.07	1155	3.7
E	18-38	2.6	0.03	1284	2.4
Bt	38-51	20.6	0.02	3417	9.7
2C	51-200+	41.2	0.03	43185	13.9
		Pedon 10,10			
Ap1	0-19	1.8	0.03	1218	3.9
Ap2	19-34	2.1	0.04	1236	3.3
2Bt1	34-69	35.8	0.03	21565	18.7
2Bt2	69-96	40.4	0.12	27117	29.7
		Pedon 12,0			
Ap1	0-18	2.9	0.02	293	2.0
Ap2	18-37	2.8	0.04	371	2.8
C1	37-64	2.4	0.02	212	2.2
C2	64-85	2.6	0.03	169	0.2
C3	85-106	2.2	0.03	160	0.6
C4/Ab	106-112	4.8	0.03	240	1.7

Table 3-3--Continued.

Horizon	Depth (cm)	Clay (%)	EC* (dS/m)	TP (ug/g)	CEC (cmol/kg soil)
			Pedon 12,0		
Ab1	112-119	10.5	0.05	579	6.3
Ab2	119-137	17.4	0.02	593	7.9
C'1	137-149	8.1	0.01	259	3.3
C'2	149-156	6.4	0.01	221	2.5
C'3	156-200+	1.9	0.01	63	0.6
			Pedon 14,10		
Ap1	0-19	5.3	0.09	1787	8.3
Ap2	19-37	5.4	0.06	1651	8.2
A	37-62	2.4	0.03	900	3.8
Ab	62-104	0.9	0.01	578	1.6
Eb	104-146	2.5	0.01	538	0.9
Eb/Btb	146-173	0.4	0.01	637	0.4
Eb/Btb	173-200+	0.8	0.01	743	0.3
			Pedon 18,18		
Ap1	0-29	1.8	0.04	577	1.2
Ap2	29-37	1.4	0.04	598	2.0
AE	37-72	2.2	0.01	628	1.2
E1	72-122	2.0	0.01	557	0.5
E2	122-182	0.9	0.01	434	0.1
E/Bt	182-200+	1.8	0.01	539	0.1

* EC=electrical conductivity; TP=total phosphorus; and CEC=cation exchange capacity.

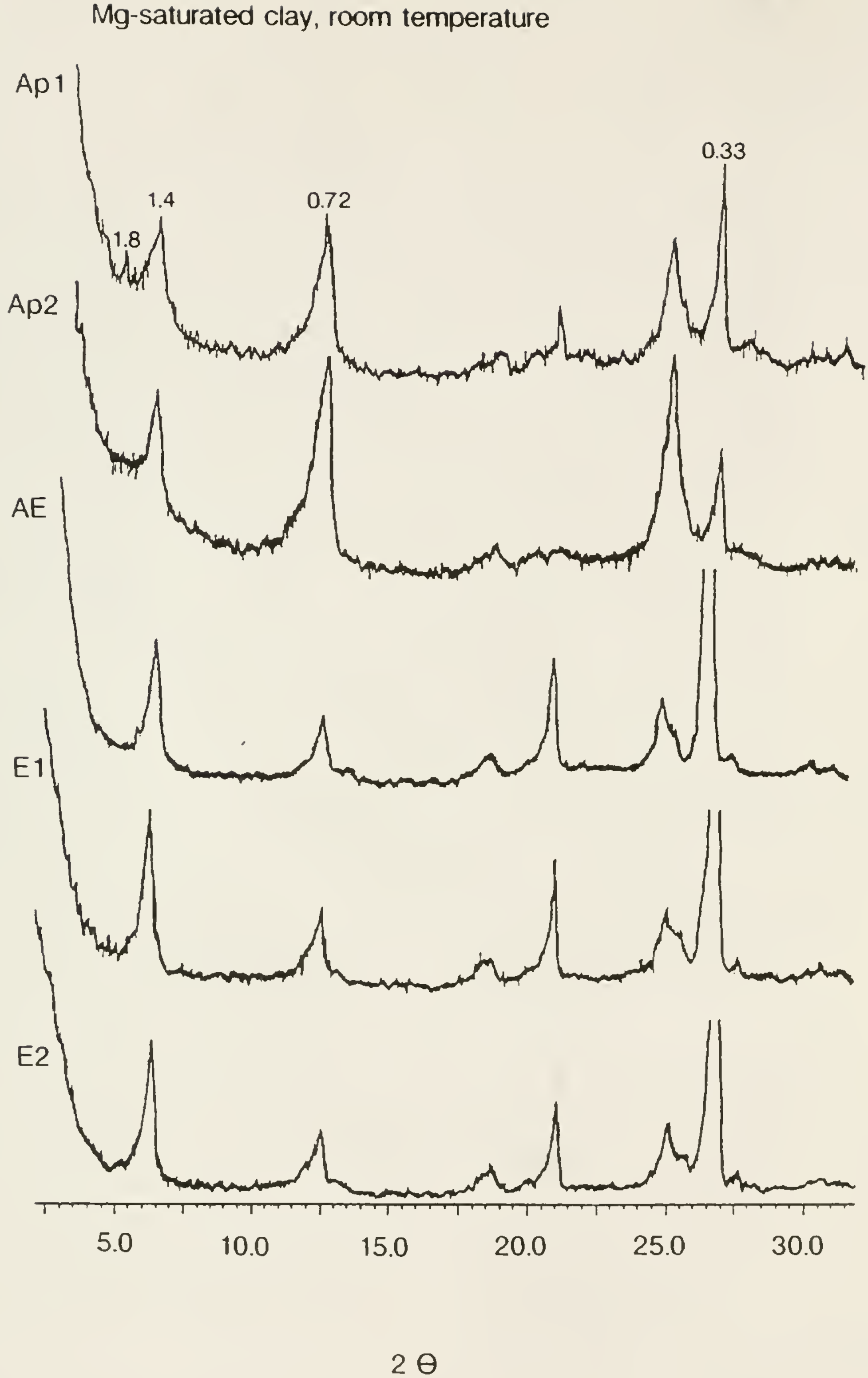


Figure 3-11. X-ray diffraction patterns of Mg-saturated, glycerol-solvated clay by horizon for pedon 0,16 (Otela soil) at the Quincey plot.

Figure 3-11--continued.

Figure 3-12. X-ray diffraction patterns of Mg-saturated, glycerol-solvated clay by horizon for pedon 2,21 (Pedro soil) at the Quincey plot.

The morphological boundary between the E3 and Bt1 horizons was abrupt, wavy, and was located below 1 m. The clay content increased from 1% in the E3 horizon to 16% in the Bt1 horizon (Table 3-3). The E*Bt1 interface (radar interfaces between soil horizons will be indicated by a *, i.e., E*Bt) on the graphic profile (Fig. 3-3a) was broad and black which indicated a high contrast between over and underlying materials (Ballard, 1983; Shih and Doolittle, 1984; Collins and Doolittle, 1987; and Hearns, 1987). A second graphic radar interface was between the Bt2 and Bt3 horizons at a depth between 190 and 200 cm, Fig. 3-3a. The Bt3 horizon doubles in clay content and CEC and has a thirty fold increase in TP compared to the Bt2 horizon (Table 3-3). Naturally high TP values are normally associated with phosphatic materials (Pirkle, 1956; Pirkle et al., 1965; Scott, 1983; Ovalles and Collins, 1986). The moisture content of each horizon also increased as the clay content increased with increasing depth which enhanced the contrast between adjacent layers on the graphic profiles.

The ECs were all less than 0.03 dS/m, (Table 3-3). Electrical conductivity is important because soils with high ECs rapidly dissipate the radar's energy and restricts probing depth (Shih et al., 1986). The soils in the QP all had ECs less than 0.12 dS/m (Table 3-3), which was low enough to not affect the GPR signal (Shih et al., 1986).

Pedon 2,4

Pedon 2,4 was classified as the Shadeville series (loamy, siliceous, thermic Arenic Hapludalfs), Fig.3-4b. The Shadeville soil represents a commonly occurring soil on the CLP (Chapter 2, Table 2-8). The combined thickness of the A and E horizons of the Shadeville soil was less than 1 m.

The first graphic radar interface was between the E2 and Bt1 horizons (Fig. 3-4a). The morphological boundary between the E2 and Bt1 horizons was abrupt, smooth (Fig. 3-4b). The clay content increased from 2.2 to 17.6% from the E2 to the Bt1 horizon (Table 3-3). The E2*Bt1 graphic interface was broad, black, continuous, and smooth (Fig. 3-4a). A second possible graphical interface was between the Bt2 and 2Bt3 horizons at a depth of 50 to 60 cm (Fig. 3-4a). The morphological boundary between the Bt2 and 2Bt3 horizons was abrupt, wavy (Table 3-3). The clay content of the soil increased from 18.0% in the Bt2 horizon to 30.0% in the 2Bt3 horizon (Table 3-3). No graphical interfaces were detected for the lower 2Bt3*2Bt4 or 2Bt4*3R horizons. This indicated that most of the radar's energy had been reflected back to the antenna or the 2Bt and 3R horizons rapidly dissipated the radar's energy.

Pedon 2,21

Pedon 2,21 was classified as a fine-loamy, siliceous, hyperthermic, Ultic Hapludalfs (Fig. 3-5b). It is a variant

to the Pedro series. The Pedro series is defined as "Typic" at the subgroup level but the sampled pedon was classified as "Ultic". Pedon 2,21 also differed from the Pedro series by a lack of a R horizon. The 2C horizon, in pedon 2,21, was described as having firm to very firm consistence. The majority of the Pedro soils on the QP were underlain by limestone. The Pedro soil was not extensive on the CLP but was normally an inclusion in the Jonesville-Otela-Seabroad map unit (Chapter 2).

Pedon 2,21 had only one graphical radar interface (Fig. 3-5a); a composite between the E, Bt, and 2C horizons. The Bt and 2C horizons were shallow enough to the soil surface that their graphic interface merged with the surface interface. As a result, the radar could not distinguish the interface between the Bt and 2C horizons. The Bt horizon was only 10 cm thick which is less than the resolution of the 120-MHz antenna. Therefore, the Bt and 2C horizons were recorded on the GPR graphic profile as one interface (such interfaces will be denoted by a "-", i.e., Bt-2C). The E*Bt-2C graphic interface (Fig. 3-5a) was thin, black, and irregular which indicated an irregular morphological boundary between the E, Bt, and 2C horizons. The clay content increased from 2.6% in the E horizon to 41.2% in the 2C horizon (Table 3-3). The TP content increased from approximately 1200 ug/g in the A and E horizons to more than 43,000 ug/g in the 2C horizons. The 2C horizon was composed

of a soft, white phosphatic rock with vertical cracks and fractures filled with a brownish yellow (10YR 6/6) sandy clay. These features were shown on the graphical radar profile as hyperbolic interfaces (Fig. 3-5a). The 2C horizon attenuated the radar's signal and as a result, the graphical image was white below the E*Bt-2C interface.

Pedon 10,10

Pedon 10,10 was identified as the Bushnell series (fine, mixed, hyperthermic Albaquic Hapludalfs), Fig. 3-6b. The Bushnell soil was not extensive on the CLP. Generally, the Bushnell soil was an inclusion in the Shadeville-Otela-Levyville map unit (Chapter 2). In the QP, the Bushnell soil lacked an E horizon and, thus, the Ap horizon directly overlain the 2Bt1 horizon. The first-radar interface was between the Ap2 and 2Bt1 horizon and was within 50 cm of the soil surface (Fig. 3-6a).

The morphological boundary between the Ap2 and 2Bt1 horizon was abrupt, wavy (Fig. 3-6b). The clay content increased from 2.1 to 35.8% from the Ap2 to the 2Bt1 horizon (Table 3-3). The Ap2*2Bt1 graphic interface was thin and black and varied from irregular to smooth (Fig. 3-6a). The CEC and EC values were higher in the 2Bt horizon of the Bushnell soil than any of the other sampled soils (Table 3-3). The TP content increased from approximately 1200 ug/g in the Ap horizons to more than 21,000 ug/g in the 2Bt horizons (Table 3-3). A second graphical interface can be

observed at approximately 1 m in Fig. 3-6a. The interface was between the 2Bt2*3Cr-3R horizons. The interface is gray to grayish black, discontinuous, and irregular.

Pedon 12,0

Pedon 12,0 was classified as a hyperthermic, coated Typic Quartzipsamments (Fig. 3-7b). No soil series has been established that was similar to pedon 12,0. Pedon 12,0 had multiple radar interfaces at depths ranging from 1 to more than 2 m (Fig. 3-7a). The morphological boundary between the C3 and C4/Ab horizon was abrupt and all other lower horizon boundaries were gradual (Fig. 3-7b). The first-radar interface was grayish black, broad, smooth to wavy, mostly continuous, and at depths ranging from 100 to 150 cm (Fig. 3-7a). The clay content increased from approximately 2% in the C horizons to approximately 17% in the Ab2 horizon (Table 3-3). Other radar interfaces observed below the first were grayer, less continuous, and more wavy than the first graphical interface.

Pedon 14,10

Pedon 14,10 was classified as a hyperthermic, coated Typic Quartzipsamments (Fig. 3-8b). Presently, no soil series exists similar to pedon 14,10. Pedon 14,10 was not extensive on the CLP, but was an inclusion in some map units. Pedon 14,10 was chosen because it represented a defined component of the landscape, a sinkhole. The radar interface in Fig. 3-8a, was probably due to a change in the

moisture content from the lower A horizons into the upper E horizons. The thick A horizons of pedon 14,10 were not detected by the GPR.

Pedon 18,18

Pedon 18,18 was classified as the Candler series (hyperthermic, uncoated Typic Quartzipsamments) Fig. 3-9b. Candler was one of the dominant soils on the CLP (Chapter 2, Table 2-8). The prominent feature of the RC for Pedon 18,18 was the lack of any continuous radar interfaces within 2 m. The point interfaces at approximately 2 m were lamella in the E/Bt horizon (Fig. 3-9a).

Radar Interfaces

Based on the information obtained from the 7 representative pedons, depths to three radar interfaces were estimated for each of the 437 observation stations. Soils with no radar interfaces were assigned an arbitrary depth of 285 cm, which was the vertical limit of the GPR survey. The regression equation that was used for estimating interface depths was assumed to maintain linearity for all radar interface depths below the first interface. Velocity changes in wave propagation could occur between materials of contrasting electrical properties and confound the depths estimated for deeper underlying horizons (Ulriksen, 1982). But, it was assumed that the effects of the various soil properties on the velocity of wave propagation below the first interfaces were negligible or equal.

A surface-net diagram of surface elevations is presented in Fig. 3-13. The X elevation was 15.3 m with a CV of 5.1% (Table 3-4). The majority of the QP was nearly level with small depressions and hills scattered throughout. The QP sloped from the northwest to the southeast. The p-values, associated with the Shapiro-Wilks test (SAS,1988) for normality, indicated that the elevation and depth interface data were non-normally distributed (Table 3-4), and therefore the X, Md, and Mo are all given as a measure of the sample populations central tendencies.

The conclusion in Chapter 2, that the present surface does not reflect the subsurface variability of the QP, was supported by the large variations in CVs for the interface data (Table 3-4). Coefficient of variation has been used by researchers as a measure of variation between sample populations (Drees and Wilding, 1973; Rao et al., 1979; Wilding and Drees, 1983). The surface elevation CV was 5% and the CVs for all the other interfaces were greater than 43%. Explanations for the variations between the present surface and subsurface are (a) differential karst activity has lowered the present surface and/or (b) Pleistocene seas have mantled a paleokarst surface with sand to create the present surface. The variations between the present surface and the depth to diagnostic subsurface horizons supported the use of grid mapping (Chapter 2) and the introduction of the intriplex map unit in this type of landscape.

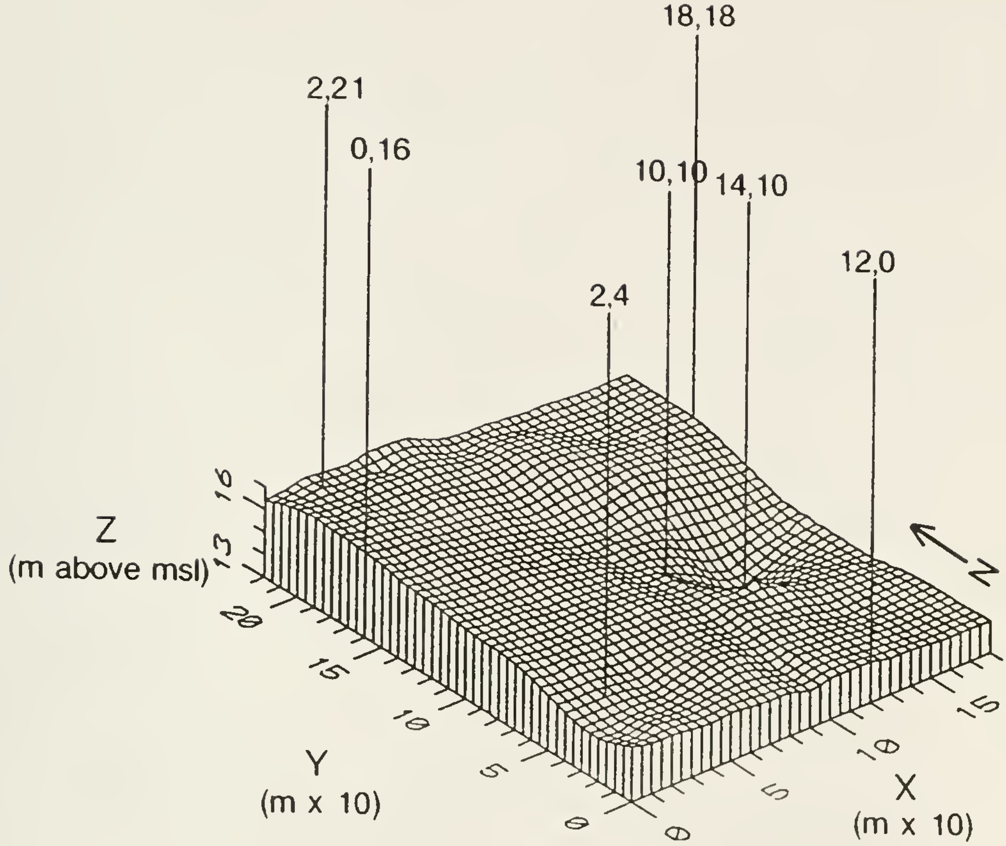


Figure 3-13. Computer-generated surface-net diagram of surface elevations above mean sea level (msl) for the Quincey plot. Sampled pedon locations are posted above the diagram. Vertical exaggeration is 10% of horizontal scale.

Table 3-4. Selected statistics of surface elevations, first-radar interface (1RI), second-radar interface (2RI), and third-radar interface (3RI) for the 437 observation stations on the Quincey plot.

Variable	n	* X	Md	Mo	SE	CV (%)	p-values
		-----------cm-----------					
Surface Elev.	437	1531	1530	1560	3.7	5	0.0002
1RI	390	114	102	96	2.7	44	0.0
2RI	290	119	99	89	3.7	53	0.0
3RI	168	128	131	41	4.3	43	0.0001

* X=mean of sample population.
Md=median of sample population.
Mo=mode of sample population.
CV=coefficient of variation.
p-values=probabilities associated with the Shapiro-Wilk W-statistic.
SE=standard error of the mean.

First-radar interface

The surface-net diagram in Fig. 3-14, represents the topography of the first-radar interface (1RI) for the 437 observation stations. The interfaces represented morphological boundaries between A and Bt horizons, E and Bt horizons, Bt and R horizons, Bt and 2Cr horizons, C and Ab horizons, and soils with no contrast between subsurface horizons. Forty-seven of the soils in the QP did not have a continuous radar interface (no contrast between subsurface horizons) and, therefore, were assigned an arbitrary interface depth of 285 cm.

The X depth to the 1RI was 114 cm with a CV of 44%. The 1RI represented a surface that was highly variable and had many of the features associated with karst, i.e., sinkholes.

The 1RI was significant for both pedologic and geologic reasons. Pedologically, the surface represented all the diagnostic subsurface horizons and the implications associated with their development. One pedologic example is the eluviation and illuviation of clay particles to form an argillic horizon and subsequent formation of an abrupt boundary between the E and Bt horizons.

One geologic implication was that the abrupt boundary between the E and Bt horizons was not related to soil forming processes but instead represented separate sedimentary events. Understanding the relationships between

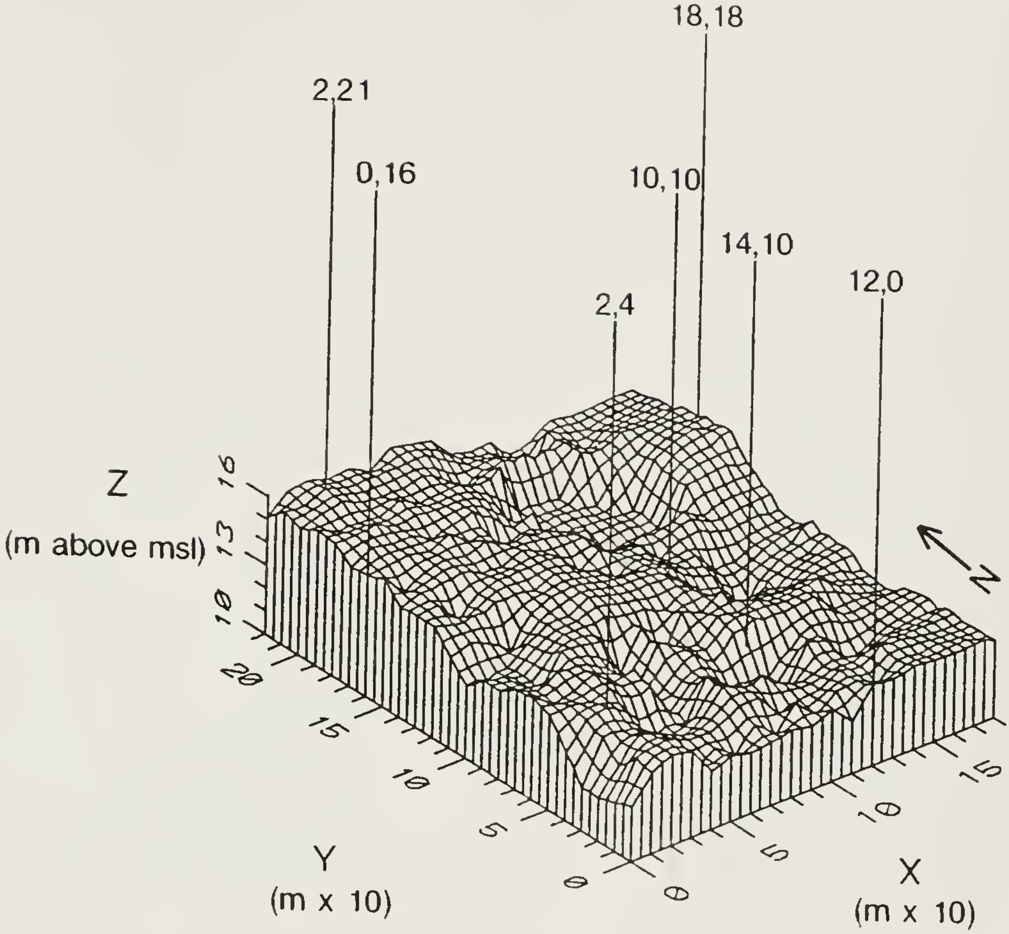


Figure 3-14. Computer-generated net diagram of the first-radar interface based on elevation above mean sea level (msl) for the Quincey plot. Sampled pedon locations are posted above the diagram. Vertical exaggeration is 10% of horizontal scale.

the geologic and pedologic influences in the QP are key in understanding the development of both the soils and landscapes on the CLP.

Another feature of the 1RI, was the large depression in the northeastern section of Fig. 3-14. The surface-net diagram representing the present surface (Fig. 3-13), did not indicate this subsurface feature. The depression may represent a paleo-feature that has subsequently been filled with sediments to form the present surface.

<u>Second-radar interface</u>

The second-radar interface (2RI) (Fig. 3-15), represented the surface of the more clayey Bt horizons, phosphatic 2C horizons, and/or limestone (i.e., the 2Bt horizons in the Shadeville and Bushnell soils; and the Bt, 2C, and R horizons in the Pedro soil). One hundred of the observation stations did not have a 2RI. The X depth to the 2RI was 119 cm with a CV of 53%. This was the highest CV for any of the radar-interface data.

The difference between the X depths for the 1RI and 2RI was only 5 cm. This difference reflected the number of A*2Bt and Bt*C-R interfaces that occurred at depths less than 50 cm in the 1RI data set.

The horizons composing the 2RI had high clay contents, extremely high TP values, and no HIV. These properties are all indicative of Pliocene to Miocene sediments (Vernon, 1951; Pirkle, 1956; Pirkle, 1965; Scott, 1983; Ovalles and

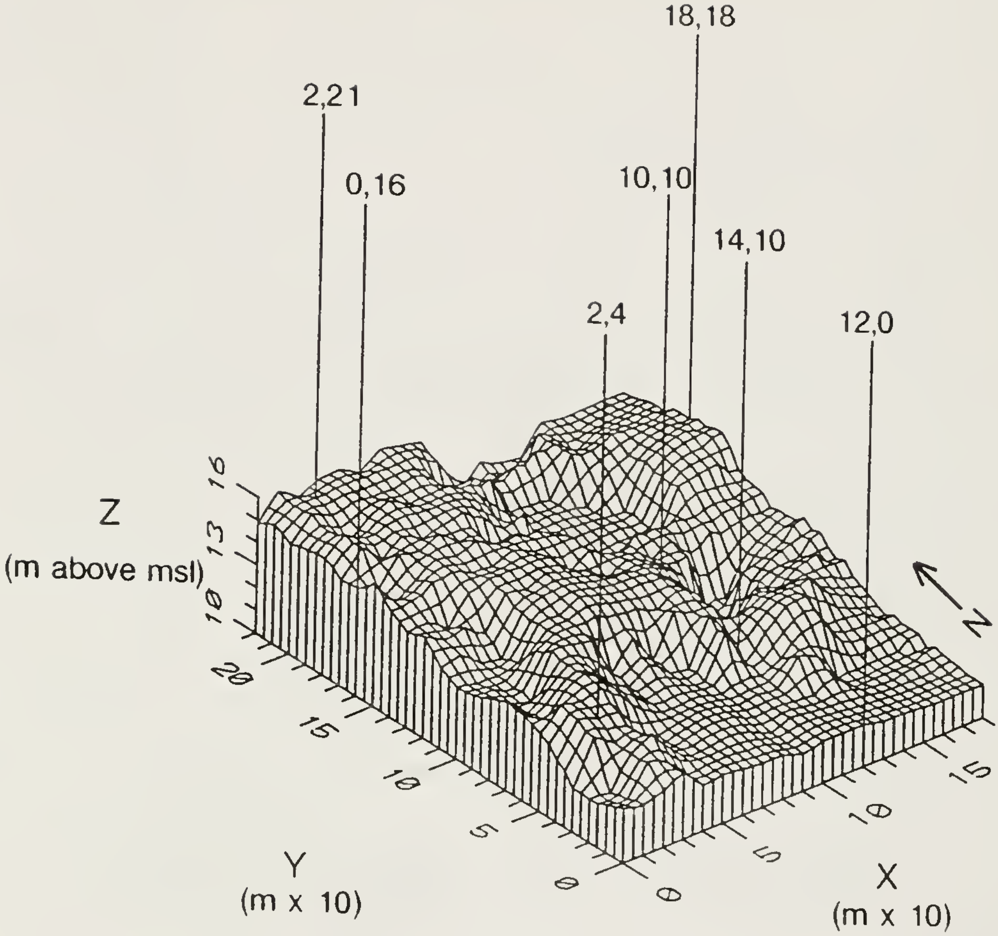


Figure 3-15. Computer-generated net diagram of the second-radar interface based on elevation above mean sea level (msl) for the Quincey plot. Sampled pedon locations are posted above the diagram. Vertical exaggeration is 10% of horizontal scale.

Collins, 1985). Sections of the 2RI may represents a paleo-surface.

Clayey subsurface horizons and limestone were not apparent within 285 cm in the southern portion of the QP in Fig. 3-15. This area may represent a paleo-depression that had subsequently filled-in. This conclusion was based on the stratification observed in pedon 12,0.

Third-radar interface

The third-radar interface (3RI) represented the upper boundaries of all R, Cr, and 2C horizons (Fig. 3-16), i.e., the 3R horizons in the Bushnell and Shadeville soils and the Bt, 2C, and R horizons in the Pedro soils. One-hundred and sixty-eight observation stations were underlain by limestone or phosphatic materials. The 3RI was irregular and, for the most part, was directly overlain by the clayey horizons represented by the 2RI (Fig. 3-15). The X depth to the 3RI was 128 cm with a CV of 43%. The Mo of 41 cm indicated that a significant percentage (41%) of the soils had 3RIs within 50 cm, i.e., Bushnell and Pedro soils. The surface-net diagram of the 3RIs represented what might have been the upper surface of the Eocene-age Ocala Group limestones (Fig. 3-16).

Radar-Grid Categories

The RCs, depths to the three radar interfaces, and data from the sampled pedons were combined with the criteria in the Official Series Descriptions (Soil Conservation Service,

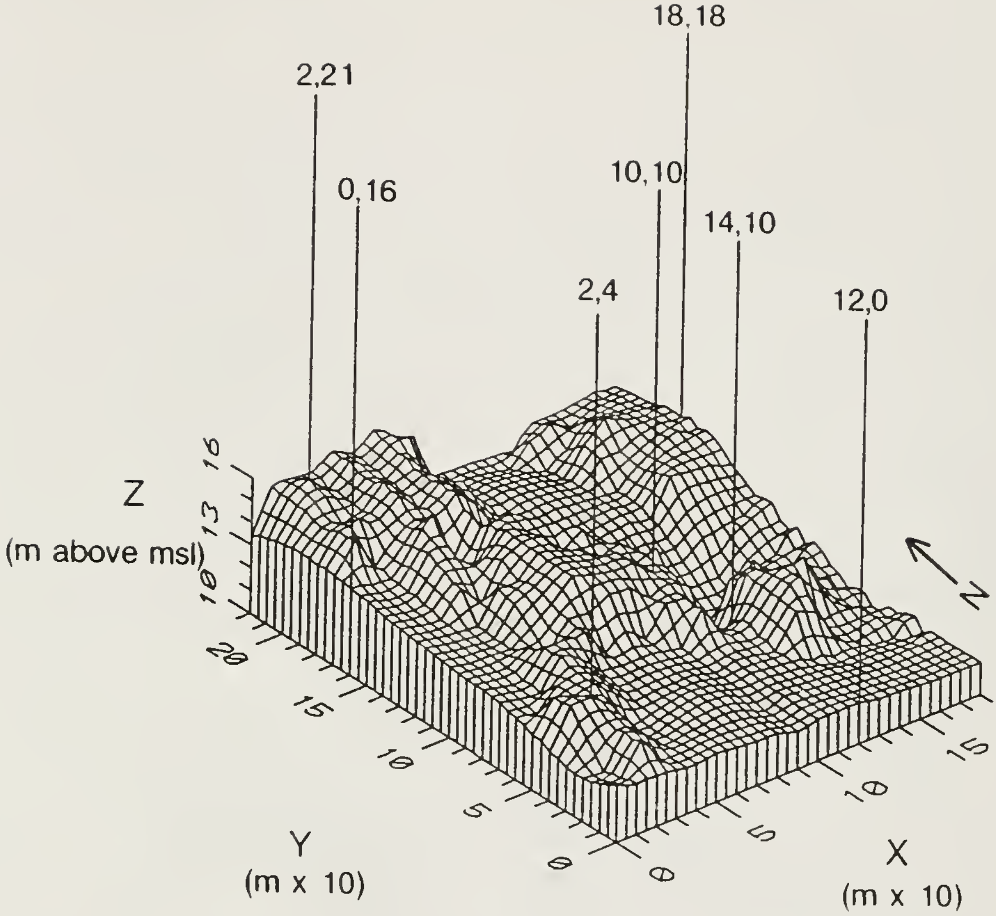


Figure 3-16. Computer-generated net diagram of the third-radar interface based on elevation above mean sea level (msl) for the Quincey plot. Sampled pedon locations are posted above the diagram. Vertical exaggeration is 10% of horizontal scale.

1988) for each of the representative soils to establish a set of RGCs. Pedons 12,0 and 14,10 were not members of an established series. Therefore, the criteria for these soils were based on the representative pedons from the QP.

The RGCs could only be defined by these series criteria: (a) presence or absence of specific horizons, (b) arrangement of horizons, and (c) depth to horizons. The depth, presence or absence, and arrangement criteria for the horizons were used because the other differentiating characteristics for the series could not be determined by visual inspection of the graphic radar profiles. Soil color, one criteria necessary to distinguish between "Pale" and "Hapl" great groups in Alfisols, could not be determined from the graphic radar profiles. Also, soil drainage classes, which are normally based on depth to gray mottles, could not be determined by GPR analysis. Subsurface horizon textures could only be estimated based on the intensity (gray to black) of the interface signals on the graphic radar profiles (Olson and Doolittle, 1985; Shih and Doolittle, 1985; Collins and Doolittle, 1987). Color, texture, and drainage determinations were extrapolated to all observation stations based on the 35 auger-hole observations. The RGCs are presented in Table 3-5.

Each observation station in the QP was assigned a RGC. Two additional RGCs, RGCs 8 and 9, were added based on

Table 3-5. Criteria for establishing radar-grid categories for the 437 observation stations on the Quincey plot.

Radar Class	*OSD	Radar-Grid Category	Summary of Criteria
A	Otela	1	-A and E horizons > 1 m in combined thickness. -E/Bt interface between 1 and 2 m. -second Bt interface not required. -no R horizon interface within 2 m.
B	Shadeville	2	-A and E horizons < 1 m in combined thickness. -E/Bt interface between 0.5 and 1 m. -second Bt interface not required. -Bt/R horizon interface at a depth > 1 m.
A	Pedro	3	-E/Bt-R interface at a depth < 0.5 m. -Cr and/or R interface < 0.65 m due to cyclic variation of soil.
D	Bushnell	4	-the Ap-E/Bt interface < 0.5 m. -Cr and/or R interface > 0.5 and < 1 m.
E	No Established Series	5	-multiple interfaces at a depth > 1 m. -no R interface allowed. -no Bt interface allowed.
F	No Established Series	6	-no diagnostic horizon interfaces within 2 m. -adjacent interfaces dip downward.
G	Candler	7	-no diagnostic horizon interfaces within 2 m. -E/Bt point interfaces at depths > 1 m.

*OSD= Official Soil Series Description.

interpretations of the graphic profiles. The establishment of these two additional RGCs was the result of extrapolation of the ground-truth data to the graphic radar profiles. Soils in RGC 8 were RGC 1 soils that had a R horizon interface between 1 and 2 m. Radar-grid category 9 soils were like RGC 5 soils except that the C4/Ab horizons were above 1 m.

After RGCs were assigned to the 437 observation stations, soil borings were made at 44 of the observation stations to check the validity of each assigned RGC. Eleven of the 44 observation stations assigned a RGC, or 25%, were misclassified. Five of the 11 misclassifications were due to incorrectly assigning RGC 5 to the observation stations. The correct classification was either RGC 1 or 7. Five other misclassifications were due to an error in the estimated depths to the 1RI.

The C3*C4/Ab radar interfaces in the RGC 5 soils (Fig. 3-7), were not easily distinguished from the E3*Bt1 radar interfaces in the RGC 1 soils (Fig. 3-3). Observation stations were misclassified as RGC 1 soils when only 1 radar interface was produced by the C and Ab horizons instead of the multiple radar interfaces expected. Proper assignment of RGC 1 and 5 soils was based on area of occurrence in the QP and associated RGCs. Radar-grid category 5 soils were also confused with RGC 7 soils at some locations.

Some of the RGC 7 soils had multiple radar interfaces. These interfaces were normally associated with RGC 5 soils, but no diagnostic soil horizons were found at these observation stations when soil borings were made. The multiple radar interfaces were attributed to electrical noise in the radar system, reflections of deeper or adjacent horizons, or slight changes in moisture content and/or sand content with depth.

Five other misclassifications were due to an error in the estimated depths of the 1RIs. Radar-grid categories were assigned to each observation station based on the estimated depths of specific soil horizons. The 1 and 2 m depths were a primary distinguishing characteristics between the RGCs (Table 3-5). Problems were encountered when the estimated depths of the 1RI were either close to the 1 or 2 m depths. The error between the predicted and actual depths of the 5 observed observation stations ranged from 5 to 9 cm. The 1RI depths for these 5 observation stations were all near 1 or 2 m. The Md depth for all the 1RIs was 102 cm and the Mo was 96 cm. A 5 to 9 cm error in the estimated depth of the 1RI could easily result in a taxonomic misclassification of the soil at the observation station.

The final misclassification was between RGC 3 and 4. Determining the difference between the Pedro and Bushnell soils from the graphic profiles was difficult due to the

merging of the surface and subsurface radar signals (Figs. 3-5 and 3-6).

The 11 observation stations that were misclassified were corrected and the information used to re-evaluate the RGCs for the QP. Of the remaining 393 observation stations, only 10 were reassigned to new RGCs.

Spatial characteristics of the radar-grid categories

A plot of the RGCs for the QP is presented in Fig. 3-17. For statistical purposes, the sample populations of estimated depths to radar interfaces were limited between 34 and 285 cm. Radar interface depths were limited to more than 34 cm below the soil surface due to the resolution of the 120-MHz antenna, and less than 285 cm, which was the depth of the radar survey.

Radar-grid category 6 was dropped from the spatial study because it only occurred once. Pedon 14,10 (RGC 6) was sampled because of its landscape position. Radar interfaces were not observed at 47 of the 437 observation stations. Forty-six of these profiles belonged to RGC 7 and one to RGC 6. The p-values associated with the Shapiro-Wilks W test indicated that all the data within each RGC were non-normally distributed (Table 3-6). The X, Md, and Mo are presented along with the SE and CV for comparisons (Table 3-6).

Elevation. The X for surface elevations in each RGC ranged from 14.6 to 15.5 m (Table 3-6). Radar-grid

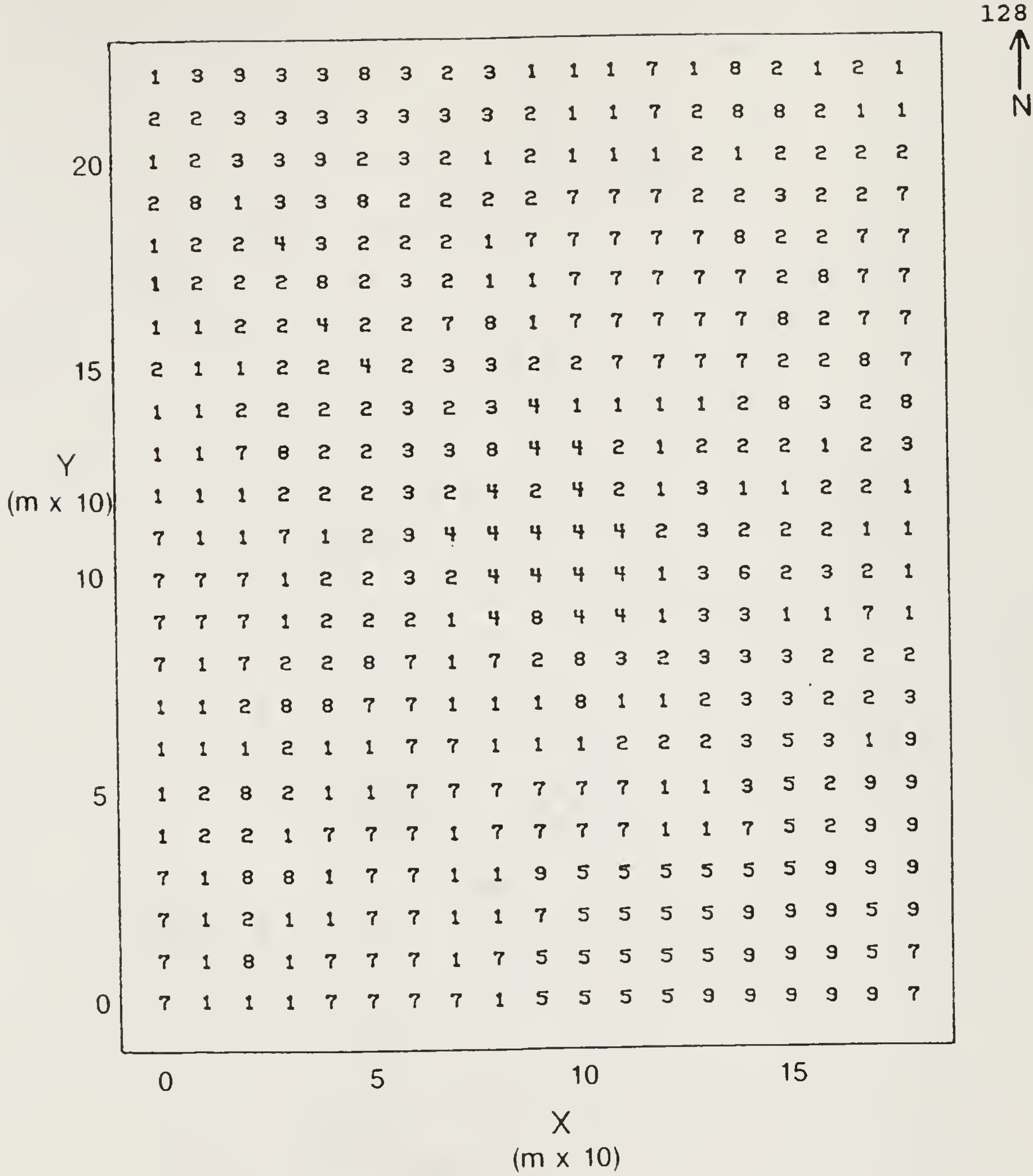


Figure 3-17. Plot of the radar-grid categories for the Quincey plot.

Table 3-6. Selected statistics of surface elevations, first-radar interfaces (1RI), second-radar interfaces (2RI), and third-radar interfaces (3RI) for each radar-grid category (RGC) on the Quincey plot.

Variable	RGC	n	*X	med	mod	SE	CV	p-values
			------------m------------					
Surface Elev.	1	103	15.3	15.3	15.1	.08	5	0.001
	2	109	15.5	15.6	15.6	.08	5	0.003
	3	49	15.4	15.6	16.5	.16	7	0.0001
	4	20	15.2	15.0	14.9	.12	4	0.0571
	5	24	14.6	14.7	14.8	.04	2	0.0392
	7	38	15.2	15.2	15.0	.09	4	0.0326
	8	26	15.5	15.5	15.4	.10	3	0.0090
	9	21	14.6	14.5	14.5	.06	2	0.1232
			-----------cm-----------					
1RI	1	103	138	134	112	2.7	20	0.0001
	2	109	85	86	84	1.1	14	0.0001
	3	49	53	46	41	2.3	30	0.0001
	4	20	53	46	34	4.4	37	0.0088
	5	24	158	153	127	7.4	23	0.4555
	7	38	228	221	205	3.9	11	0.0429
	8	26	116	109	107	2.5	11	0.0002
	9	21	83	79	76	2.5	14	0.0658
2RI	1	103	204	205	285	6.1	30	0.0001
	2	109	107	89	84	5.1	49	0.0
	3	49	68	51	41	7.2	74	0.0001
	4	20	53	46	34	4.4	37	0.0088
	5	24	277	285	285	4.4	8	0.0001
	7	38	276	285	285	2.7	6	0.0001
	8	26	121	112	107	3.7	16	0.0001
	9	21	269	285	285	11.5	20	0.0001
3RI	1	103	271	285	285	3.5	13	0.0
	2	109	198	169	285	7.4	39	0.0
	3	49	111	64	285	12.3	78	0.0001
	4	20	87	71	34	13.2	68	0.0004
	8	26	168	172	147	6.9	21	0.0135

* X=mean of sample population.
Md=median of sample population.
Mo=mode of sample population.
CV=coefficient of variation in percent.
p-values=probabilities associated with the Shapiro-Wilk W-statistic.
SE=standard error of the mean.

categories 2, 3 and 8 occupied the highest elevations and RGC 5 and 9 occupied the lowest elevations. The CVs for elevations were all less than 8%, which indicated that in each RGC the elevations occurred within a narrow range. Since the elevation differences between the means of RGCs 1, 2, 3, 4, 7 and 8 were 30 cm or less, landscape and soil relationships at a macro-level (Chapter 2, 1:24000) appeared random. This illustrates that the present surface does not correlate well with the subsurface topography. The CV for the present land surface was much less than the CV for the 1RI which indicated that subsurface variability was much greater than that expressed by the present land surface (Table 3-4).

First-radar interface. Mean depths to the 1RI ranged from 53 to 228 cm (Table 3-6). The CV for the 1RI was 45% (Table 3-4), but most of the CVs for the individual RGCs were less than 25% (Table 3-6). This indicated that depth was less variable within RGCs than between RGCs. The 1RIs of radar-grid categories 3 and 4 had CVs of 30 and 37%, respectively, and their X, Md, and Mo were also the most variable. The X depth to the 1RI in RGCs 3 and 4 was 53 cm, which was slightly greater than the 50 cm depth allowed by the RGC (Table 3-5). The Md and Mo depths for RGCs 3 and 4 were less than the 50 cm limit. The error in the estimated depth can be accounted for by the limitations of the 120-MHz antenna to resolve soil horizons at depths less

than approximately 34 cm. Radar-grid categories 3 and 4 were assigned to those observation stations where the subsurface interfaces merged with the surface pulses.

The X depth to the 1RI for RGC 7 was 228 cm, which is greater than the ground-truth data that was observed (Table 3-6). For the depths between 200 and 285 cm, it was assumed that the regression equation used for estimating depths maintained linearity due to the homogeneity of the fine sand propagating material. Forty-five percent of the RGC 7 soils had a 1RI between 200 and 230 cm and the difference between these RGC 7 soils and RGC 1 soils was primarily due to the irregular nature of the 1RI (Fig. 3-14). If the 1RI was above 2 m, the observation station was assigned RGC 1, but if the interface was greater than 2 m, RGC 7 was assigned.

<u>Second-radar interface</u>. The X depth to the 2RI was 119 cm (Table 3-4) and the X depths to the 2RI within each RGC ranged from 53 to 277 cm (Table 3-6). The CV for the 2RI was 53% (Table 3-4) and the CVs for the 2RI within each RGC ranged from 6 to 74% (Table 3-6). Radar-grid category 3 exhibited the highest CV and one of the highest SE.

The X, Md and Mo were similar for some of the RGCs in both the 2RI and 1RI, i.e., RGCs 2,3,4, and 8. The X was influenced by the complete range of depths estimated from the graphic profiles, whereas, the Md and Mo were not. The E*2Bt interfaces were not only part of the 2RI, but also

the 1RI as indicated by values associated with the X, Md, and Mo for RGC 4.

Radar-grid category 2 had a different X but similar Md and Mo for the 1RI and 2RI (Table 3-6). The Shadeville soil, which was represented by RGC 2, was defined as having an E*Bt interface between 50 and 100 cm with a Bt*2Bt interface not required. The Bt*2Bt interface represented the more clayey, phosphatic materials. The Xs for the 1RI and the 2RI were 85 and 107 cm, respectively. A 2RI (Bt*2Bt or Bt*R) was expected in most profiles, but the Md and Mo values indicated that in some profiles, the Shadeville soils were more similar to the Bushnell soils. The similarities between the Md and Mo of the 1RI and 2RI indicated that some of the 1RIs represented morphological boundaries between E and 2Bt horizons. In these profiles, the Shadeville soils were more similar to the Bushnell soils except for depth to the Bt horizon.

Radar-grid categories 5, 7, and 9 had X values greater than 200 cm and Md and Mo values of 285 cm. Values of 285 cm were not used in the UNIVARIATE procedure as previously discussed.

<u>Third-radar interface</u>. The X depths to the 3RI ranged from 87 to 271 cm and CVs ranged from 13 to 78% (Table 3-6). Radar-grid categories 5, 7, and 9 did not have limestone R horizons within a depth of 285 cm. Modal values of 285 cm indicated that some pedons of RGC 1, 2, and 3 were also not

underlaid by limestone within 285 cm. The conclusion for RGC 3 was that some pedons had an E*Bt-R interface and others an E*Bt-2C interface.

<u>Nearest-neighbor analysis</u>

After each observation station was assigned a RGC, the arrangement of points in each category was evaluated. The evaluation was conducted to determine if the soils of the QP occurred at random or were structured at the scale of observation. The calculated and theoretical distances for each type of arrangement (Dobs, Dran and Ddis) are presented in Table 3-7. Plots of each RGC are presented in Figs. 3-18 to 3-20. The R-values for each RGC were tested at the .05% level of significance.

Based on the nearest-neighbor analysis, the null hypothesis could not be rejected for RGCs 3, 7 and 8. The spatial patterns of RGCs 3, 7 and 8 are presented in Fig. 3-18. Pedro soils were represented by RGC 3 (Fig. 3-18a). The Pedro soils appeared to be clustered and have a NW to SE trend, but a significant number of observations were scattered resulting in the ratio of Dobs to Dran to be near 1 (Table 3-7). Pedro soils occurred on the high landscape positions in the NW part of the QP and around the rim of the large sinkhole (coordinate 15,11), Fig. 3-10. The Pedro soils occurred in conjunction with a topographic high in the 3RI (Fig. 3-21). The high, more level landscapes in Fig. 3-

Table 3-7. Distance statistics for pattern analysis using nearest-neighbor analysis for each radar-grid category (RGC) on the Quincey plot.

RGC	n	Dobs*	Dran*	Ddis*	R*	Results
1	103	10.9	9.8	21.1	1.12	dispersed
2	109	10.9	9.5	20.5	1.16	dispersed
3	49	12.5	14.2	30.6	0.92	random
4	20	11.1	22.2	47.8	0.49	clustered
5	24	10.0	20.3	43.6	0.49	clustered
7	84	11.4	10.9	23.5	1.01	random
8	26	18.2	19.1	41.1	0.94	random
9	21	11.9	21.7	46.7	0.55	clustered

* Dobs=Observed mean nearest-neighbor distance between observation stations.
Dran=Expected mean nearest-neighbor distance for a random arrangement of observation stations.
Ddis=Expected mean nearest-neighbor distance for a dispersed arrangement of observation stations.
R=Nearest-neighbor index (Dobs/Dran).

Figure 3-18. Individual plots of radar-grid categories 3, 7, and 8 that have a random spatial arrangement of points as determined using nearest-neighbor analysis for soils at the Quincey plot.
a) Spatial arrangement of radar-grid category 3;
b) Spatial arrangement of radar-grid category 7;
c) Spatial arrangement of radar-grid category 8.

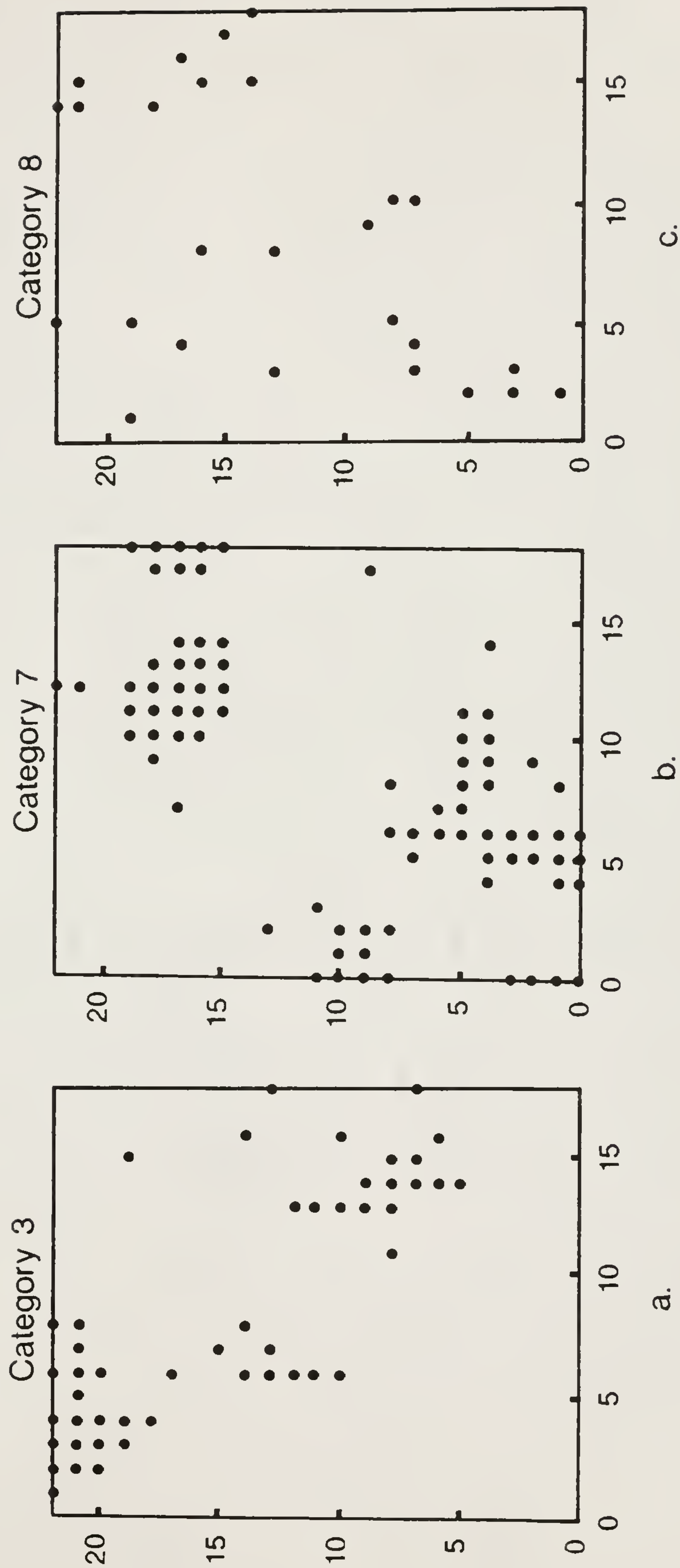
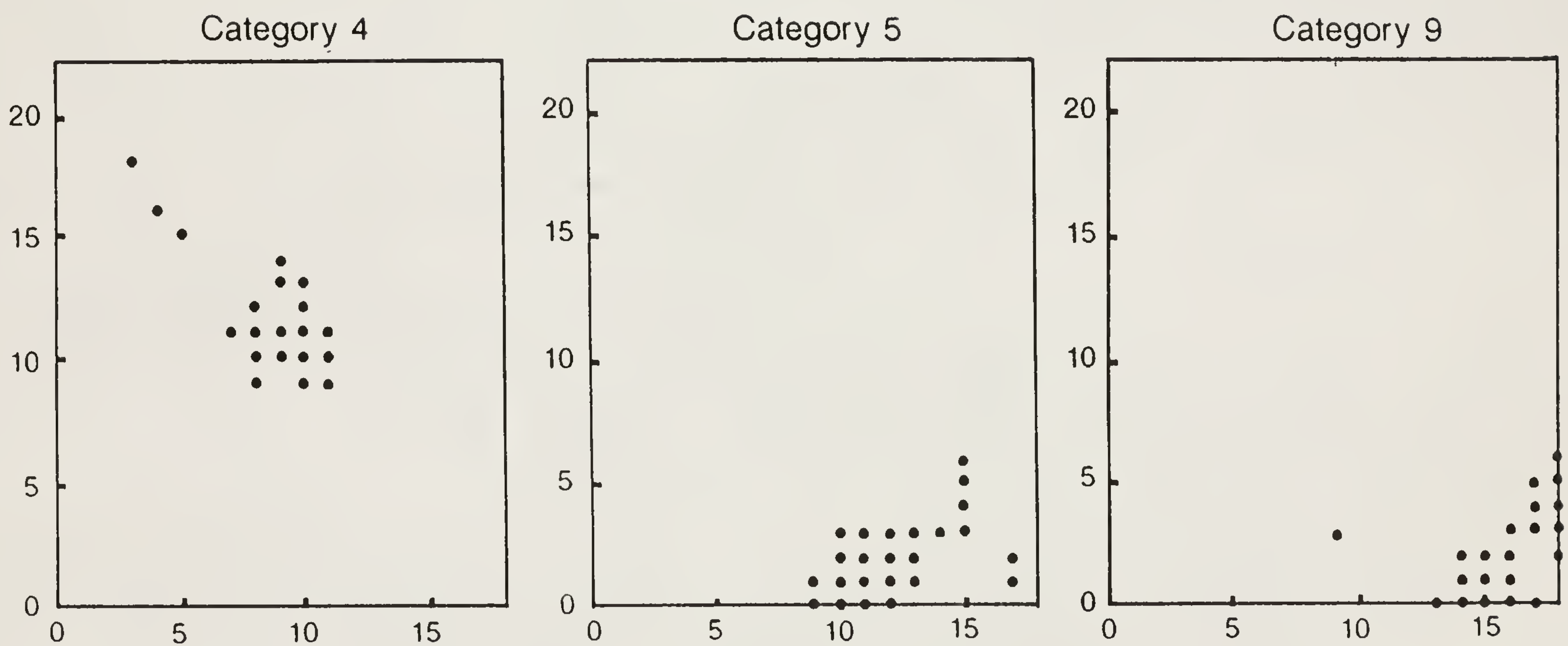

Category 3
a.
Category 7
b.
Category 8
c.
0
5
10
15
20

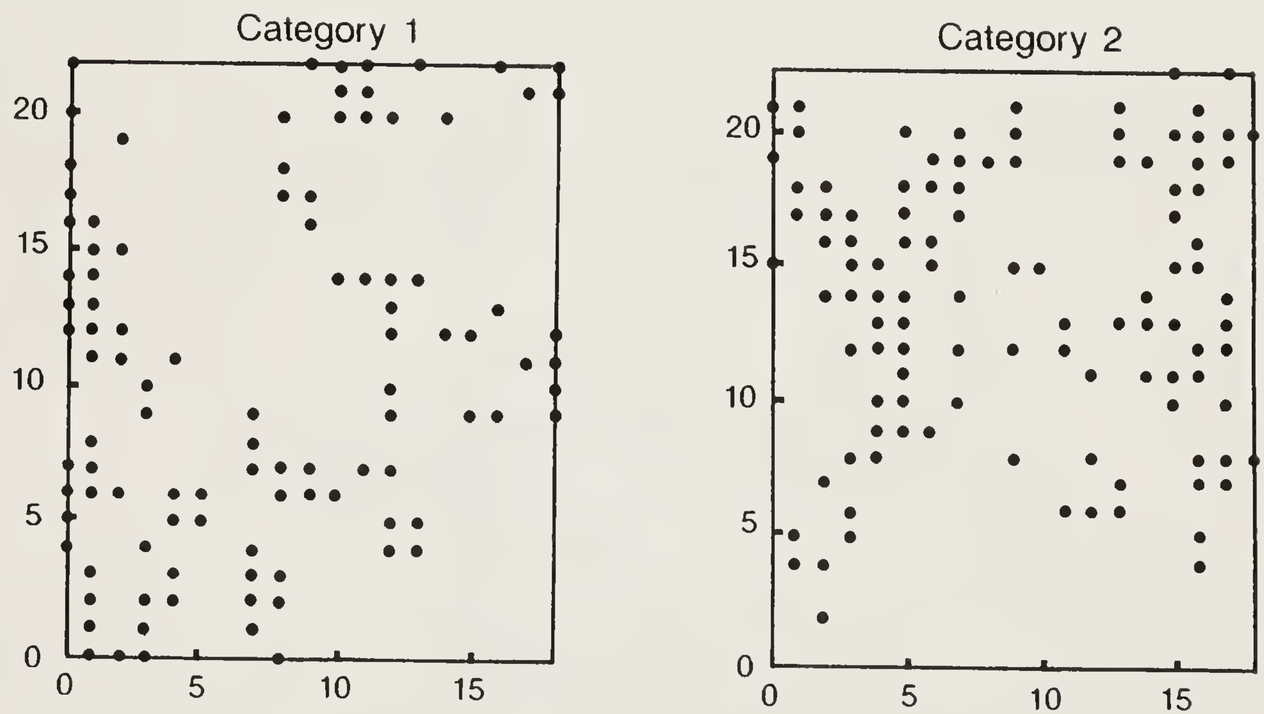
Figure 3-19. Individual plots of radar-grid categories 4, 5, and 9 that have a clustered spatial arrangement of points as determined using nearest-neighbor analysis for soils at the Quincey plot.

a) Spatial arrangement of radar-grid category 4;
b) Spatial arrangement of radar-grid category 5;
c) Spatial arrangement of radar-grid category 9.



a. b. c.

Figure 3-20. Individual plots of radar-grid categories 1 and 2 that have a dispersed spatial arrangement of points as determined using nearest-neighbor analysis for soils at the Quincey plot.
a) Spatial arrangement of radar-grid category 1;
b) Spatial arrangement of radar-grid category 2.



a.

b.

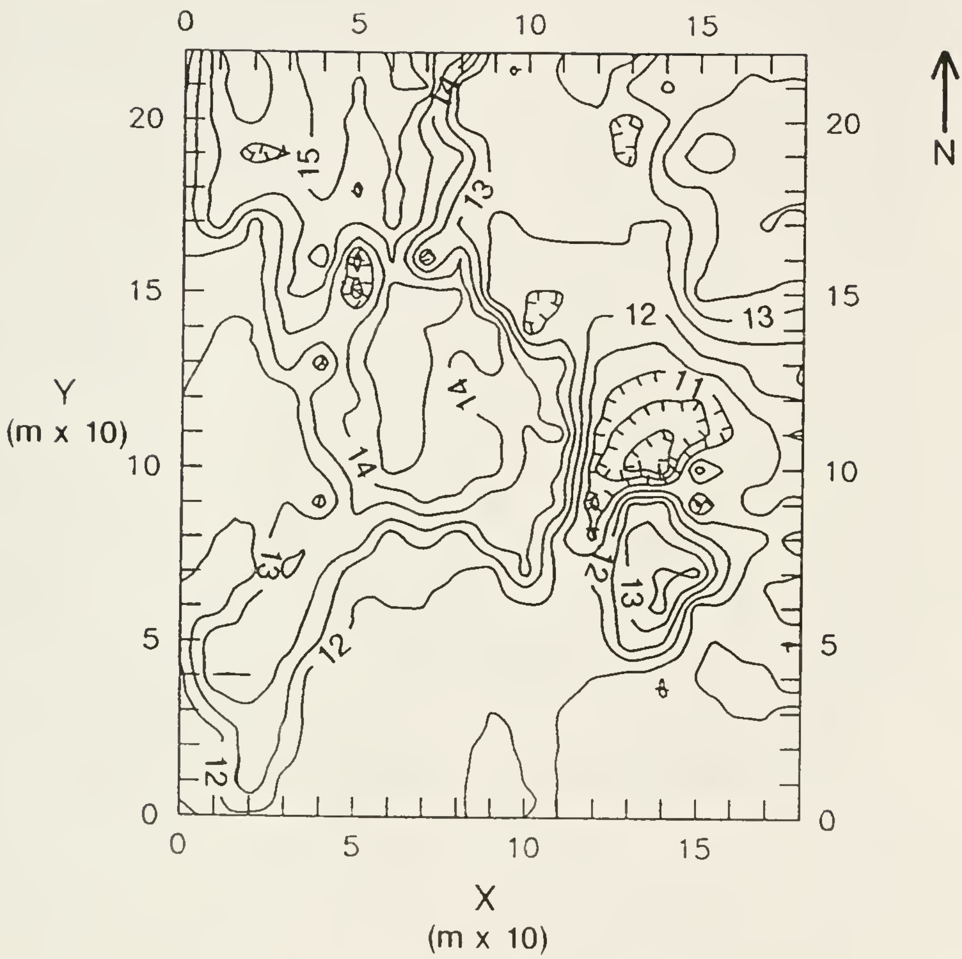


Figure 3-21. Computer-generated contour map of the third-radar interface based on elevations above mean sea level for the Quincey plot (contour interval 0.5 m).

10, also occurred in conjunction with the topographic high in the 3RI (Fig. 3-21).

Candler soils were represented by RGC 7. The Candler soils also appeared clustered by visual inspection of Fig. 3-18b, but a significant number of observations were scattered throughout the QP, so that the value of R was approximately 1. A comparison between Fig. 3-10, Fig. 3-18b, and Fig. 3-22 illustrated that RGC 7 occurred in relation to the 1RI and not the present land surface. A majority of the points in RGC 7 occurred in subsurface depressional features (Fig. 3-22). The Candler soils occurred as both clustered and random pedons in the QP.

Radar-grid category 8 appeared to be the most random of the three (Fig. 3-18c). Category 8 represented soils with Bt and R horizons between depths of 1 and 2 m. The occurrence of RGC 8 in the QP landscapes would be difficult to predict based on its spatial arrangement. Category 8 soils would be a common inclusion in RGC 2 and less common in RGCs 1 and 7.

Radar-grid categories 4, 5, and 9 were determined to be significantly clustered in the QP (Fig. 3-19). R-values were all less than 0.6. Bushnell soils were represented by RGC 4 and were clustered in the central portion of the QP (Fig. 3-19a). This area was represented by fine sand A horizons directly overlying clayey 2Bt horizons. A comparison between Fig. 3-19a and Fig. 3-10 showed that the

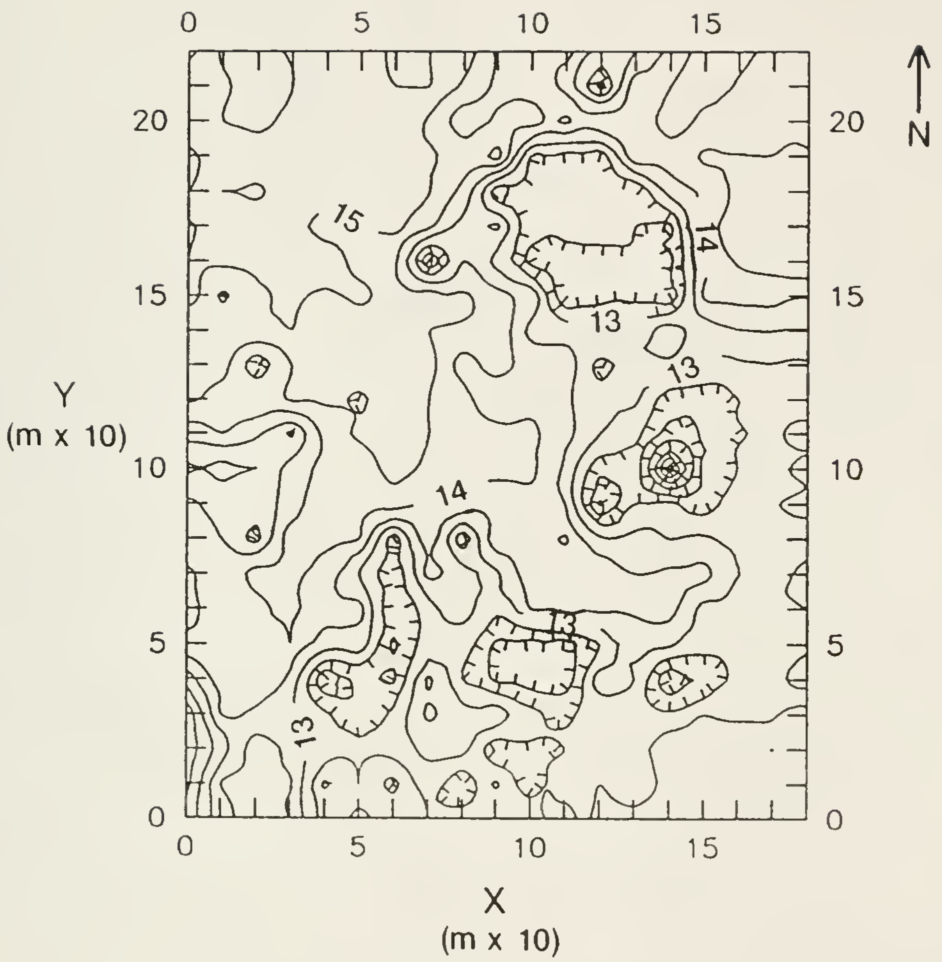


Figure 3-22. Computer-generated contour map of the first-radar interface based on elevations above mean sea level for the Quincey plot (contour interval 0.5 m).

Bushnell soils occurred on the rim area of the present sinkhole. The 3RI contour illustrated that the area where the Bushnell soils had occurred were on the sideslopes of the topographic high in the 3RI (Fig. 3-21).

Radar-grid categories 5 and 9 were confined to the southeast part of the QP (Figs. 3-19b and 3-19c, respectively). These soils occupied the lowest portions of the present landscape except for the large sinkhole (Fig. 3-10). The area immediately to the east and southeast of the QP was at a lower elevation than the QP (Fig. 3-2). The buried horizons represented by RGCs 5 and 9 were believed to have been caused by infilling of a former depression or drainageway leading into these lower areas.

Otela and Shadeville soils were represented by RGCs 1 and 2, (Figs. 3-20a and 3-20b), respectively. The spatial arrangements of points in both RGCs were dispersed (Table 3-7). The Otela soils occurred at the periphery of the topographic highs in the 2RI and 3RI, Figs. 3-23 and 3-21, respectively. Possible hypothesis for this arrangement are (a) the topographic highs in the 2RI and 3RI are older paleosurfaces and the parent materials for the Otela soils were deposited adjacent to the older surface by a separate geologic event, (b) same as (a), but the parent materials for the Otela soils were deposited across the entire QP and were subsequently eroded, (c) the Otela soils only represent increasing depths to the subsurface horizons moving

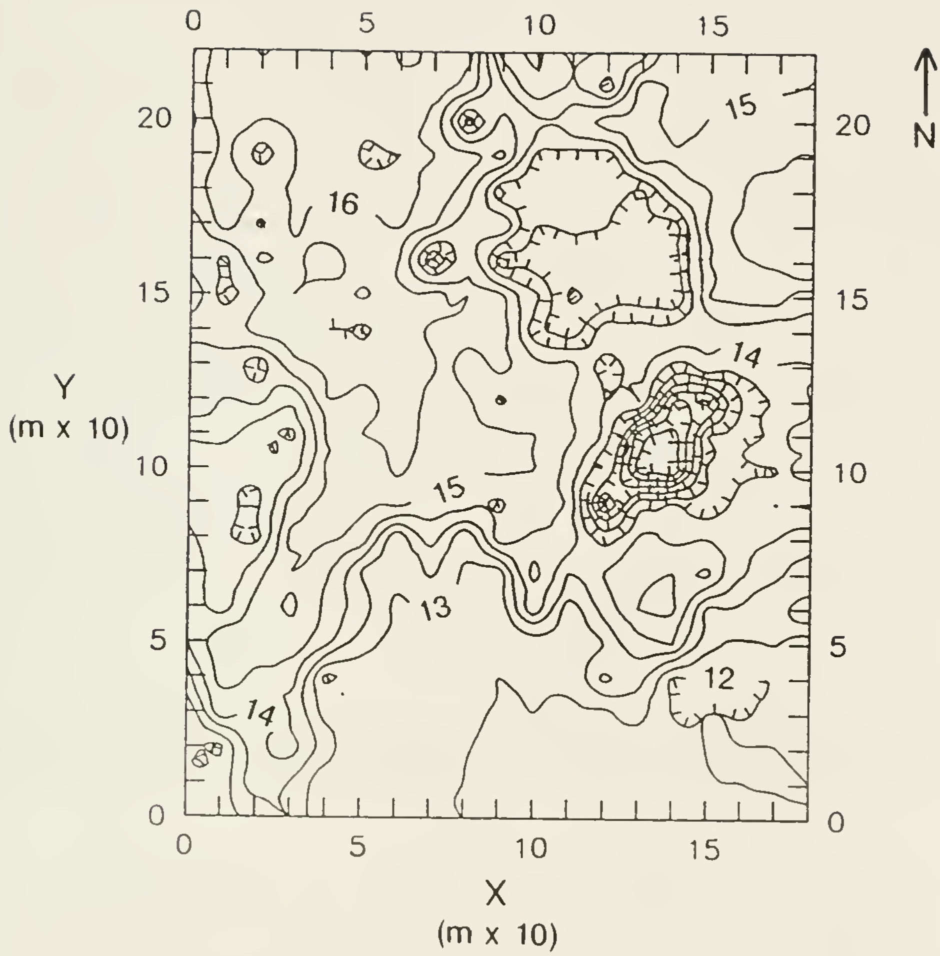


Figure 3-23. Computer-generated contour map of the second-radar interface based on elevations above mean sea level for the Quincey plot (contour interval 0.5 m).

laterally off the summit of the topographic highs, or (d) all the parent materials were deposited together and differential solution has lowered the landscape and was responsible for the observed arrangement.

The Shadeville soils occurred atop the topographic highs and adjacent to the present sinkhole (Fig. 20b, Fig. 3-21, and Fig. 3-23). The Shadeville soils were normally underlain by limestone. Hypothesis for the occurrence of Shadeville soils and limestone to form topographic highs are (a) the clayey Bt horizons of the Shadeville soils were deposited upon a paleo-karst surface and has since protected the limestones from solution, thereby creating a topographic high as adjacent areas were solutionally lowered, and (b) the clayey horizons were deposited in topographically low areas during the Miocene or Pliocene and are now topographically high due to landscape inversion.

Conclusions

Soils representing the dominant soils of the CLP were studied in detail in the 4-ha QP. Ground-penetrating radar data were used to study the subsurface variations of soil horizons. The present surface of the QP does not reflect the irregular nature of the subsurface horizons. Ground-penetrating radar data allowed for interpretations of subsurface karst features and soil horizon stratigraphy. Relationships between graphic radar profiles were difficult

to establish when soils with dissimilar horizons had similar radar signatures or subsurface horizons were close enough to the surface to merge with the surface pulse.

The higher, more level landscapes in the QP occurred in conjunction with the upper surface of the 3RI. The Bushnell and Shadeville soils, which were associated with RGCs 4 and 2, occurred on these landscapes. The more clayey Bt horizons, in these soils, capped the limestone and provided protection to the underlying soluble limestone.

Mulitple hypothesis were proposed to explain the occurrence of the soils within the QP but these hypothesis must be substantiated by laboratory data. The pedologic processes and geologic influences must be differentiated to understand the soils of the QP and therefore the soils of the CLP.

CHAPTER 4
GENETIC PATHWAYS OF SOIL FORMATION ON THE CHIEFLAND LIMESTONE PLAIN

Introduction

Pedogenic research on karst has concentrated on the origin of the soil parent materials (Ahmad and Jones, 1969; Ballagh and Runge, 1970; Smith et al., 1972; Olson et al., 1980; Frolking, 1982). These authors asked the question, were the soils a residual product of the weathered limestone or were the soils formed in parent materials that had been transported and deposited over the limestone?

Soils research in Barbados and Jamaica indicated a residual origin for the soils formed on karst. Ahmad and Jones (1969) reported that the soils overlying limestone on Barbados were residual based on soil mineralogy and insoluble residues. The amount of insoluble residues in the limestone ranged from 0.7 to 2.5%. Kaolinite was the dominant clay mineral in the soils on the humid landscapes and montmorillonite was the dominant clay mineral in the soils on the more arid landscapes.

The bauxite deposits of Jamaica were considered to be residual limestone products (Smith et al., 1972). The amount of limestone insoluble residues, which was the parent

material for the bauxite, was 0.07%. Also, the limestone denudation rate was reported to be 40 to 70 mm per 1000 years. Based on the data, the amount of bauxite in any single deposit could not be accounted for as residual from the underlying limestone. Therefore, Smith et al. (1972) purposed that the bauxite was transported through the groundwater system and concentrated in the lower areas of the present landscape. This model explained the thickness of the bauxite deposits relative to the amount of limestone and insoluble residues required for the formation of the observed bauxite deposits.

Research conducted on karst in selected areas in the mid-western United States indicated that the soils of those areas were not developed from residual limestone materials (Ballagh and Runge, 1970; Olson et al., 1980; Frolking, 1982). The "Terra Rossa" soils in these karst areas were considered to be developed in alluvial overwash that had originated from outside the karst areas. This conclusion was based primarily on clay mineralogy and carbon-14 dating. Insoluble residues of the limestones ranged from 0.6 to 11.8%.

Clay mineralogy, insoluble residues, elemental analysis, stratigraphy, carbon-14 dating, denudation rates, and oxygen isotope ratios have been used to answer the

questions concerning the genesis of soils overlying limestone in karst areas.

Once the soil-limestone genesis question has been answered, a model for pedogenesis can be purposed. Two possible pathways exist for the model, (a) if the soil developed as a residual weathering product of the limestone then the model would concentrate only on the soil-limestone system, but (b) if the soil was not related to the limestone then the model would have to include not only the limestone system, but also the provenance of the soil sediments and the interaction of the two systems on each other. Arnold (1965) concluded that multiple hypothesis or pathways was the best way to explain pedogenic processes.

The Coastal Plain Province, in the United States, is characterized by sandy to clayey unconsolidated marine and fluvial sediments (Fennenman, 1938; Thornbury, 1965). By this definition, these sediments are water deposited and are not considered residual weathering products of underlying bedrock. Generally, the bedrock within the Coastal Plain Province is located tens to hundreds of meters below the soil surface. Therefore, the question of soil formation as a result of in-situ bedrock weathering should not be considered because of the definition of Coastal Plain sediments.

However, the "Bare Karst" regions of west-central Florida are characterized by geologically thin sandy to

clayey sediments (0 to 10 m) overlying limestones (Sinclair and Stewart, 1985). Geologists have determined that these sediments overlying the karst were marine in origin (Cooke, 1945; Vernon, 1951; Pirkle, 1956; Pirkle, 1957; White, 1958; Pirkle et al., 1965; Puri et al., 1967; White, 1970; Williams et al., 1977). Therefore, attempts to model the soil-limestone system must explain the origin of the sediments and the interactions between the soil and the underlying limestone.

Wang and Arnold (1973) gave two fundamental considerations when evaluating pedogenesis. They were to (a) determine the uniformity of the soil system, and (b) determine the initial state of the soil system. The uniformity and initial states of Coastal Plain sediments have been related to soil textures, which were correlated with the nature of the sedimentary unit; and soil mineralogy which was related to the mineralogy of the original sediments (Pirkle, 1960; Altschuler et al., 1963; Fiskell and Carlisle, 1963; Daniels and Gamble, 1978). The intensity of the soil forming processes on the Coastal Plain sediments has been reported to be controlled by the hydrologic characteristics of the soil system (Carlisle, 1962; Fiskell and Carlisle, 1963; Daniels et al., 1970; Daniels and Gamble, 1978; Harris and Carlisle, 1987; Harris et al., 1987). Daniels and Gamble (1978) concluded that time, parent material, and soil moisture were the most

important soil forming factors when considering distribution of soils on Coastal Plain landscapes. These concepts were developed on stable landscapes within the Coastal Plain Province. Little research has been conducted on soil formation on bare karst in the Coastal Plain Province.

The objectives of this research were to (a) determine the origins of the soils on the CLP, (b) propose a parent material-time sequence model, and (c) propose genetic pathways for formation of the soils on the Chiefland Limestone Plain.

Materials and Methods

Location of the Study Area

The study area was on the Chiefland Limestone Plain (CLP) in Levy County, Florida (Fig. 1-1). The CLP is divided into a northern and southern half. This study was confined to the northern half of the CLP. A subarea, referred to as the Quincey plot (QP), was selected for more detailed study within the CLP and was located in the northeastern part of the CLP on the farm of Mr. Frank Quincey (Fig. 1-1).

Levy County is characterized by long, warm summers and mild winters. The mean annual temperature was 21°C and the average annual rainfall was 1387 mm from 1841 to 1982. Elevations ranged from 8 to 20 m in a SW to NE trend across

the CLP. The northern half of the CLP encompassed approximately 28,000 ha.

Physiography and Geology

Levy County is part of the Coastal Plain Province as defined by Fennenman (1938) and Thornbury (1965). The Coastal Plain Province is characterized by sandy to clayey unconsolidated marine and fluvial sediments. Vernon (1951) subdivided Levy County into two major physiographic areas; the Terraced Coastal Lowlands and the River Valley Lowlands. The CLP is part of the Terraced Coastal Lowlands (Fig. 1-2). The Terraced Coastal Lowlands include four coastwise terraces; (a) the Coharie at 66 m, (b) the Okefenokee at 45 m, (c) the Wicomico at 30 m, and (d) the Pamlico at 7.5 m.

The CLP is a broad, relatively flat, surface of unconsolidated marine sediments overlying the Eocene-age Ocala Group limestones. The CLP was correlated by Vernon (1951) as a submarine limestone shelf formed as part of the Wicomico shoreline. However, evidence from Alachua, Gilchrist, and Levy Counties suggested that the CLP should be considered part of the Penholoway shoreline (R.C. Lindquist, 1987, personal communications). The Wicomico and Penholoway terraces were both correlated with the Sangamon interglacial period (Cooke, 1939; Vernon, 1951).

The type of karst on the CLP is normally referred to as "bare or thinly covered limestone" (Sinclair and Stewart, 1985). They defined bare or thinly covered limestone as

being covered by materials ranging in thickness from less than 0.3 to about 8 m. Karst features are common on the CLP. Bowl-shaped depressions and small hills make up the dominate landforms on the CLP. Most of the bowl-shaped depressions are classified as solution sinkholes (Sinclair and Stewart, 1985). Solution sinkholes are formed when lateral variations in solution are minimum. The depressions caused by the sinkholes vary in diameter from less than 10 m to more than 100 m. Minor features of the CLP are vertically and horizontally oriented solution channels, limestone outcrops, and drowned caves.

Undifferentiated Miocene-, Pliocene-, Pleistocene-, and Holocene-age sands and clays make-up most of the surficial parent materials for soil development.

Selection of Soils

Seven pedons were sampled in the 4-ha QP. These seven soils represented the major soils occurring on the CLP. Ground-penetrating radar data were used to help select the soil sampling sites as discussed in Chapter 3.

Laboratory Analysis

The 7 selected pedons were described and sampled by horizon. Samples were collected at deeper depths in some pedons and given numeric labels. Bulk samples were air dried for 1 to 2 weeks. Most samples were hand ground and sieved in order to prevent breakdown of gravels larger than 2 mm. Particles larger than 2 mm were weighed and saved for

future analysis. After most particles larger than 2 mm were removed, the more clayey samples were ground with an electric grinder. A 1,000 g subsample from the original dried and sieved bulk field sample was collected by using a sample halving device. A sample halving device was used each time a soil sample was needed for a particular analysis. The halving procedure was used to reduced error associated with subsampling.

Particle size was determined using the pipette method (Day, 1965) and fine clay content was determined using the USDA method (Soil Survey Staff, 1984).

Subsamples were finely ground to pass through a 250-um sieve for determination of total phosphorus (TP) and organic carbon (OC) contents. Total phosphorus content was determined using the alkaline-oxidation method developed by Dick and Tabatabai (1977) as modified by Walter (Collins, 1977). Organic carbon content was determined using the acid-dichromate method (Soil Survey Staff, 1984). Soil pH was determined potentiometrically in water, 1 M KCL, and 1 M $CaCl_2$ in a 1:1 soil/liquid ratio.

Cation exchange capacity (CEC) was calculated by summation of the extractable bases (Na, K, Mg, and Ca), using as an extractant 1 M NH_4OAc pH 7.0; and extractable acidity, using 0.25 M $BaCl_2$ TEA pH 8.2 (Soil Survey Staff, 1984). Electrical conductivity (EC) measurements were made using a 1:1 ratio of soil to water.

The A and E horizon samples were treated with NaOCl to remove organic matter in preparation for mineralogical analysis. Samples were pretreated with Na citrate-dithionate-bicarbonate to remove oxide coatings (Mehra and Jackson, 1960). Organic matter and iron were removed because of the confounding effects of these cementing agents on dispersion and the proper orientation of clay on the ceramic tile.

Sand was separated by wet sieving. Silt and clay were dispersed by adjustment of the suspension pH to 10 with Na_2CO_3 and then separated by centrifugation and decantation.

Oriented mounts of coarse and fine clay fractions were prepared by depositing approximately 250 mg from the suspension onto a ceramic tile under suction, saturating with Mg or K, washing free of salts, and adding glycerol to the Mg-saturated samples.

Clay minerals were identified from x-ray diffraction (XRD) patterns of Mg-saturated clay (air dry and $110^{o}C$) and air dry, 100^{o}, 300^{o}, and $550^{o}C$ heated, K-saturated clay. X-ray diffraction analysis was conducted using a Nicolet I2 computer-controlled system. Samples were scanned at $2^{o}2\theta$ per minute using CuK-alpha radiation. Minerals were identified from XRD patterns using differentiating criteria outlined by Whittig and Allardice (1986).

Heavy minerals were separated following the methods of Carver (1971). One gram of very fine sand from each horizon

was added to tetrabromoethane (specific gravity 2.876) in nalgene centrifuge tubes. The samples were centrifuged at 2000 rpm for 10 minutes which concentrated the heavy minerals at the bottom of the centrifuge tubes while the light minerals remained in suspension. The bottoms of the centrifuge tubes were frozen with liquid nitrogen and the light minerals were decanted. The heavy minerals were washed with methanol, dried, and weighed. The percent total heavy minerals for each horizon was determined. Qualitative evaluation of the heavy minerals was made using a petrographic microscope. The very fine sand fraction was chosen because of the relative abundance of heavy minerals in this fraction (Carlisle, 1962; Eichenholtz, 1989).

Quantitative and qualitative evaluations of the insoluble residues were determined on limestone samples using the methods of Rabenhorst and Wilding (1984). The limestone samples were dissolved in sodium acetate for several weeks after which the remaining insoluble residues were dried and weighed. The insoluble residues were reported as a percent weight of the total original limestone sample. Particle size was determined on the insoluble residues.

Petrographic and dissecting microscopes were used to study thin sections and fine sand grains in selected horizons. Undisturbed soil samples were collected in the E, Bt, 2C, Cr, Ab, and E/Bt horizons of selected soils. These

samples were dried and impregnated under vacuum with Scotchcast resin #3 (epoxy resin). Impregnated samples were cut in rough form using a diamond saw, and then commercially cut and polished for the finished thin sections (Burnham Petrographics, Monrovia, CA 91016). Identification of oriented clay followed the general guidelines by Brewer (1976).

Results and Discussion

The locations of the sampled pedons within the QP were given in Fig. 3-10. Soil series names as related to pedon grid-coordinates and soil classification are presented in Table 4-1. Abbreviated pedon descriptions were presented in Table 3-2. Complete pedon descriptions are given in the Appendix.

Soil Morphology

Otela soil

The most prominent feature in the Otela soil was the abrupt, wavy boundary between the E3 and Bt1 horizons (Table 3-2). A 15% increase in clay content occurred across this boundary. The sand grains of the E3 horizon were clean of coatings (i.e., iron and clay) as manifested by the white color (10YR 8/1) of the grains. This indicated a zone of extreme leaching in the soil. Slower water movement across the E3 and Bt1 boundary, due to low hydraulic conductivities in Coastal Plain Bt horizons (Puckett et al., 1985),

Table 4-1. Pedon grid-coordinates, soil series, and classification for the soils sample at the Quincey plot.

Pedon grid-coordinates (X,Y)	Soil Series	Classification
0,16	Otela	Sandy, siliceous, thermic Arenic Hapludalfs +
2,4	Shadeville	Loamy, siliceous, thermic Arenic Hapludalfs
2,21	* Pedro	Fine-loamy, siliceous, hyperthermic Ultic Hapludalfs
10,10	Bushnell	Fine, mixed, thermic Albaquic Halpudalfs
12,0	None exists	Hyperthermic, coated Typic Quartzipsamments
14,10	None exists	Hyperthermic, coated Typic Quartzipsamments
18,18	Candler	Hyperthermic, uncoated Typic Quartzipsamments

\+ Classification of soil would be Grossarenic if allowed by Soil Taxonomy (Soil Survey Staff, 1975).

* The Pedro soil is a variant to the Pedro series, see page 110.

probably accounted for the effective striping of the sand grains in the E3 horizon. Mottles with a chroma of 2 were observed in the Bt2 and Bt3 horizons. Low chroma mottles normally indicate soil wetness (Soil Survey Staff, 1975).

Pedoturbation (Buol et al., 1980) was evident throughout the A and E horizons. Krotovinas were present in all E horizons and charcoal was described in the E2 and E3 horizons. Pedoturbation of soil materials between adjacent horizons tends to mask subtle discontinuities by soil welding (Ruhe and Olson, 1980; Olson and Hupp, 1986). Roots were common (Soil Survey Staff, 1981) throughout the A, E, and Bt1 horizons.

A change in structure and consistence occurred between the A, E, and Bt horizons. The structure of the A and E horizons was granular with very friable consistence. The structure of the Bt horizons was subangular blocky with friable consistence. Structural differences between the A, E, and Bt horizons were attributed to pedogenesis. Organic materials were considered to be the dominant bonding agents in the A and E horizons. Adherence between sand grains was weak and aggregates were easily broken when handled. The Bt horizons were more cohesive due to the increased clay content. Pedoturbation, wetting-drying, and other factors contributed to the formation of subangular blocky structure in the Bt horizons.

No lithological discontinuities were described in the Otela soil. The Otela soil was believed to have formed in Pleistocene-aged sediments.

Shadeville soil

Abrupt boundaries and changes in colors were prominent features in the Shadeville soil. Abrupt boundaries occurred between the E2 and Bt1 horizons; Bt2 and 2Bt3 horizons; and 2Bt4 and 3R horizons (Table 3-2). Clay contents increased by approximately 15% across these boundaries for the E2 and Bt1 horizons and 13% for the Bt2 and 2Bt3 horizons.

Colors of the A and E horizons were influenced by organic matter and lack of clay. The Ap horizons were darker due to an accumulation of organic matter and the E horizons reflected more of the quartz sand colors due to low contents of organic matter and clay. The Bt1 and Bt2 horizons were brown (10YR 5/3) with no low chroma mottles. The 2Bt3 and 2Bt4 horizons were grayer than the overlying Bt horizons. The grayer colors were attributed to an environment low in oxygen. The low chroma colors of the 2Bt horizons were attributed to low hydraulic conductivities which could indicate a discontinuity with overlying horizons. The 3R horizon was hard, white limestone.

Pedoturbation of soil materials between adjacent layers was not as evident in the Shadeville soil as in the Otela soil. Roots were observed throughout the soil, but decreased in abundance with depth.

The structures and consistences of the A, E, Bt1, and Bt2 horizons were similar to those described in the Otela soil. The size and structure of the peds in the 2Bt3 and 2Bt4 horizons was coarse, subangular blocky (Soil Survey Staff, 1981). Consistence varied from firm to friable. The size of the structure and consistence in the 2Bt horizons were attributed to high clay contents of these horizons.

Three parent materials were identified in the Shadeville soil. Thus, the horizons were described to represent differences in parent materials and time. The upper profile sequence, Ap1-Ap2-E1-E2-Bt1-Bt2, formed in a parent material of Pleistocene age. The 2Bt3-2Bt4 horizons were noted as forming in materials of Miocene and/or Pliocene ages. These clayey sediments were mixed with phosphatic rubble and were probably reworked sediments of the Hawthorn and/or Alachua formations. The 3R horizon was identified as a member of the Ocala Group Limestones of Eocene age. The identification of three parent materials in the Shadeville soil was based on the information presented in Chapter 2.

Pedro soil

The prominent features of the Pedro soil were the shallow depth and abruptness of the boundary between the Bt and 2C horizons (Table 3-2). The Pedro soil was described as shallow with a thin, discontinuous Bt horizon overlying limestone and phosphatic rubble. The boundary between the E

and Bt horizons was clear and irregular (Soil Survey Staff, 1981). An 18% increase in clay content occurred across this boundary. The 2C horizon was dominantly phosphatic materials. Vertical cracks and pockets in the 2C horizon were filled with a brownish yellow (10YR 6/6) sandy clay.

Pedoturbation of soil materials between adjacent layers was not evident in the Pedro soil that was sampled. However, mixing of soil horizons does occur when the solum of the Pedro soil is within the plow zone. Depth of plowing ranged from 18 to 37 cm. Roots were observed throughout the pedon, but decreased in abundance with depth.

The structure and consistence of the Ap and Bt horizons were similar to that described for the Otela soil. The structure of the E horizon was described as single grained with loose consistence. The Bt horizon was only 11 cm thick with moderate, subangular blocky structure. The pedogenic processes responsible for development of structure were not limited by horizon thickness. The 2C horizon was structureless. The consistence of the phosphatic material was firm to very firm. The sandy clay material was friable.

A discontinuity was described between the Bt and 2C horizons. It was believed that the 2C horizon was too low in residual materials necessary to form a Bt horizon. The Ap-E-Bt horizon sequence was believed to have formed in parent materials deposited during Pleistocene sea-level changes. The 2C horizon was believed to be Miocene in age.

<u>Bushnell soil</u>

The prominent feature of the Bushnell soil was the shallow depth to the 2Bt horizon (Table 3-2). An abrupt boundary existed between the Ap2 and 2Bt horizons. The abruptness of the boundary was not totally attributed to plowing since no evidence of the 2Bt horizon was found in the Ap2 horizon. The clay content increased from approximately 2 to 36% from the Ap2 to the 2Bt horizon.

Mixing of soil materials between adjacent layers was not evident in the Bushnell soil that was sampled. However, mixing of soil materials between horizons occurred when the 2Bt horizon was at or near the surface in the QP. Roots were observed throughout the pedon, and decreased in abundance with depth.

Structure and consistence of the Ap horizons were similar to the Ap horizons described in the Otela soil. The 2Bt horizon was similar to the 2Bt horizons of the Shadeville soil. Phosphatic rubble occurred in the matrix of the 2Bt horizon, but was not more than approximately 11% by weight. The color of the 2Bt horizon was more varied than any horizon described in the QP. Colors of the 2Bt horizon ranged from strong brown (7.5YR 5/6) to light brownish gray (2.5Y 6/2). The 2Bt horizon was underlain by limestone.

The 3Cr horizon was soft, white (10YR 8/1) limestone in contrast to the 3R horizon which was hard, white (10YR 8/1)

limestone. Differences in hardness were attributed to the degree of weathering.

A thin, discontinuous layer of very dark gray (10YR 3/1) clay was observed above the limestone in some areas of the pedon. The average thickness of this layer was approximately 5 cm and was void of materials > 2 mm.

Three discontinuities were identified in the Bushnell soil; the Ap1 and Ap2 horizons were of Pleistocene age; the 2Bt horizon would have an origin similar to the 2Bt horizon in the Shadeville soil; and the 3Cr and 3R horizons were identified as members of the Ocala Group Limestones of Eocene age.

<u>Pedon 12,0</u>

A prominent feature in Pedon 12,0 was the occurrence of multiple brown horizons in the pedon (Table 3-2). The brownish horizons were described as buried horizons. The boundary between the C4/Ab and Ab1 was abrupt, smooth. Most of the other boundaries in the pedon were gradual.

Pedoturbation was observed in all the A and C horizons and the C4/Ab horizon. Krotovinas that were 1 to 3 cm in diameter extended upward from the Ab1 horizon into the overlying horizons at angles of approximately 80 degrees. The krotovinas were filled with dark brown (10YR 3/3) sandy loam soil material similar to that found in the Ab1 and Ab2 horizons. The Ab1 and Ab2 horizons were believed to have formed during a period when the soil was in a depression and

the Ab horizons were at the surface. This belief was justified by the occurrence of fine stratification in the Ab1 and Ab2 horizons and similarities of the krotovinas to present-day crayfish burrows.

Alternating bands of very dark grayish brown (10YR 3/2), very pale brown (10YR 7/3), and light gray (10YR 7/2) fine sand were observed below the Ab horizons. The C'3 horizon was white (10YR 8/1) fine sand from 156 to more than 200 cm. The sand grains were stripped clean in this horizon which was dominated by fine sand. Prominent strong brown (7.5 YR 5/6) mottles were observed in the C'3 horizon. The occurrence of high chroma mottles in sandy soils in Florida was attributed to fluctuating water tables as described by Hurt (1988). Roots were observed in all horizons in the pedon except for the C'3. The lack of roots in the C'3 horizon supports the occurrence of a fluctuating water table in this horizon. Roots decreased in abundance with depth from the surface.

Structures and consistences were similar to those described for the other sandy horizons. The color of the Ab horizons was not explainable at the time of sampling but later was attributed to coats of organic matter.

A chrono-discontinuity was observed in the soil parent materials. This discontinuity was believed to have been created when a depression was filled with local sediments sometime during the Pleistocene to Holocene epochs.

Pedon 14,10

The most obvious features associated with Pedon 14,10 were landscape position and thickness of the A horizon (Table 3-2). Pedon 14,10 was located in the bottom of a sinkhole (Fig. 3-10). The overthickened surface horizon was stratified and had buried another soil. Accumulation of soil materials in this landscape position was not unexpected. The Ap1 and Ap2 horizons met the criteria for an umbric epipedon, but stratification was observed in the A horizon and was believed to have also existed in the Ap horizons. Obvious stratification in the Ap horizons was probably destroyed by plowing. Platy fragments of stratified soil were observed in the Ap horizon upon close examination. Boundaries between the Ap1, Ap2, and A horizons were clear, smooth. The other boundaries in the pedon below the A horizon were gradual, wavy.

Evidence of pedoturbation was observed in all horizons. Krotovina and/or charcoal were observed in the Ab and Eb horizons. Roots occurred throughout the pedon and decreased in abundance with depth.

The Eb/Btb horizon was dominantly white (10YR 8/1) fine sand with thin, discontinuous, loamy find sand lamellae. The lamellae had gleyed colors of light brownish gray (10YR 6/2). A fluctuating water table could have stripped the coatings from the sand grains and caused the reduction of iron within the lamellae. The lamellae were parallel

with the soil surface which probably indicates that they had formed after the present sinkhole had formed.

The structure of the A horizon was described as platy with friable consistence. The platy structure was attributed to the stratification of the sediments in the horizon.

A discontinuity was observed between the A and Ab horizons. The discontinuity was believed to have occurred after the depression was formed by karst activity. The sinkhole and soil were believed to be Holocene in age.

Candler soil

The most obvious feature in the Candler soil was lamellae (Table 3-2). Gradual boundaries were predominate below the plow layers.

Pedoturbation was observed in all horizons. An elliptical krotovina was described in the AE horizon. The dimensions of this krotovina were similar to the dimensions of a present day gopher-tortoise burrow. Gopher-tortoises (Gopherus polyphemus) are common in the ecological communities of the CLP (Soil Conservation Service, 1987). Tubular krotovinas were described in the E1 horizon. Most of the krotovina of this type were attributed to roots or small mammals. The southeastern pocket gopher (Geomys tuza) is a common burrowing animal on the CLP. The small sandy mounds created by this mammal are easily observed in most

pastures on the CLP. Roots were observed in all horizons and decreased in abundance with depth.

The structure and consistence of the horizons in the Candler soil were similar to those described in other sandy horizons. The E2 and E/Bt horizons were dominantly white (10YR 8/2) fine sand. Light yellowish brown (10YR6/4) loamy fine sand lamellae were described in the E/Bt horizon. Fragments of loamy fine sand and sandy loam materials were also observed in the E/Bt horizon.

No lithological discontinuities were described in the Candler soil. The sandy parent material for the Candler soil was believed to be Pleistocene in age.

<u>Parent material discontinuities</u>

Based on the soil morphology, lithological discontinuities were described in 5 of the 7 soils studied. A summary of the proposed discontinuities and sources of parent materials are presented in Table 4-2.

<u>Physical and Chemical Properties</u>

Particle-size data for the seven sampled soils on the QP are presented in Table 4-3. Total sand (TS) contents ranged from 42.0 to 98.2%. The A and E horizons of all the soils sampled were greater than 90% TS. Fine sand (FS) was the dominant sand fraction in the Bushnell, Candler, Otela, Pedro, Shadeville, and pedon 14,10 followed by very fine sand (VFS) and medium sand (MS), respectively. The Ap horizons in pedon 14,10 were higher in VFS than FS. Medium

Table 4-2. Proposed discontinuities and sources of parent materials based on soil morphology for the soils studied at the Quincey plot.

Soil	Discontinuity	Original Source+ of Parent Material
Otela	none	Pleistocene
Shadeville	A-E-Bt	Pleistocene
	2Bt	*Miocene-Pliocene
	3R	Eocene
Pedro	A-E-Bt	Pleistocene
	2C	*Miocene-Pliocene
Bushnell	A	Pleistocene
	2Bt	*Miocene-Pliocene
	3Cr-3R	Eocene
Pedon 12,0	A-C-C4/Ab	Holocene
	Ab1 to C'3	Pleistocene
Pedon 14,10	A	Holocene
	Ab to Eb/Btb	Pleistocene
Candler	none	Pleistocene

+ Epochs are used as a reference point for source of parent material.
* Sediments originated during this epoch but have since been reworked.

Table 4-3. Particle-size data for the soils studied at the Quincey plot.

Horizon#	Depth (cm)	*VC	C	M	F	VF	Total Sand	Silt	Clay
		Sand Fraction							
		%							
		Otela							
Ap1	0-18	0.0	0.6	7.7	46.7	40.8	95.8	2.5	1.7
Ap2	18-36	0.0	0.9	9.2	45.9	39.5	95.5	2.7	1.7
AE	36-59	0.0	1.2	11.5	44.7	38.0	95.4	3.0	1.6
E1	59-88	0.0	1.3	12.2	46.9	35.4	95.9	2.6	1.5
E2	88-119	0.0	1.3	11.5	45.0	38.5	96.4	2.3	1.4
E3	119-138	0.0	1.2	11.2	44.8	39.8	97.0	2.0	1.0
Bt1	138-153	0.0	1.1	8.9	34.5	37.7	82.2	1.9	16.0
Bt2	153-193	0.0	1.4	11.9	38.7	30.7	82.3	2.1	15.6
Bt3	193-200+	0.1	1.2	11.6	34.2	14.6	61.6	5.0	33.5
1601	279-305	0.7	1.8	9.9	24.6	7.7	44.7	7.0	48.3
		Shadeville							
Ap1	0-16	0.0	1.3	12.1	45.7	36.4	95.5	3.1	1.4
Ap2	16-28	0.1	1.2	11.3	45.8	37.3	95.6	1.3	3.1
E1	28-51	0.1	1.1	10.9	44.2	39.0	95.2	2.3	2.5
E2	51-74	0.1	1.2	10.7	43.1	40.5	95.5	2.3	2.2
Bt1	74-112	0.0	0.8	8.3	34.9	37.0	81.0	1.4	17.6
Bt2	112-145	0.0	0.9	9.4	36.8	33.0	80.1	1.9	18.0
2Bt3	145-183	0.4	1.8	11.8	35.8	14.2	64.1	5.9	30.0
2Bt4	183-194	0.6	1.7	7.3	21.5	11.5	42.5	7.2	50.3
3R	194+	-	-	-	-	-	-	-	-
		Pedro							
Ap	0-18	0.1	1.5	12.9	46.7	33.0	94.2	2.8	3.0
E	18-38	0.1	1.5	12.5	47.1	33.1	94.3	3.1	2.6
Bt	38-49	0.4	1.9	12.0	37.5	23.1	74.9	4.6	20.6
2C	49-200+	1.9	3.0	10.3	25.4	10.9	51.5	7.3	41.2
		Bushnell							
Ap1	0-19	0.1	1.1	11.5	47.5	34.6	94.8	3.4	1.8
Ap2	19-34	0.1	1.2	11.6	47.9	34.2	94.9	3.0	2.1
2Bt1	34-69	0.6	1.8	9.8	31.9	15.1	59.2	5.0	35.8
2Bt2	69-96	0.9	2.3	10.0	28.8	11.0	53.0	6.6	40.4
3Cr	96-126	-	-	-	-	-	-	-	-
3R	126+	-	-	-	-	-	-	-	-

Table 4-3--continued.

Horizon#	Depth (cm	*VC	C	M	F	VF	Total Sand	Silt	Clay
		-----Sand Fraction----							
		%							
		Pedon 12,0							
Ap1	0-18	0.1	0.9	10.8	40.0	43.1	94.9	2.1	2.9
Ap2	18-37	0.1	0.9	10.5	40.6	42.8	94.8	2.4	2.8
C1	37-64	0.0	0.8	9.4	38.8	44.9	93.9	3.7	2.4
C2	64-85	0.0	0.8	10.0	38.4	44.7	93.9	3.5	2.6
C3	85-106	0.0	0.8	9.5	39.8	43.6	93.7	4.1	2.2
C4/Ab	106-112	0.0	0.8	9.1	38.6	43.3	91.8	3.4	4.8
Ab1	112-119	0.0	0.9	8.3	33.1	38.9	81.1	8.4	10.5
Ab2	119-137	0.1	0.7	7.8	31.3	38.7	78.5	4.1	17.4
C'1	137-149	0.0	0.5	6.4	32.2	51.0	90.1	1.8	8.1
C'2	149-156	0.0	0.4	5.8	31.5	53.9	91.6	2.0	6.4
C'3	156-200+	0.0	0.9	14.5	71.5	10.2	97.1	1.0	1.9
1201	253-303	0.0	1.0	10.5	38.0	35.8	85.5	5.3	9.2
1202	303-342	0.1	1.2	12.0	42.3	23.1	78.6	2.8	18.6
1203	342-373	0.2	1.2	12.4	43.0	14.3	71.1	4.4	24.5
1204	373-402	1.6	3.0	11.4	33.6	13.0	62.7	6.1	31.2
		Pedon 14,10							
Ap1	0-19	0.1	0.9	9.2	35.7	40.2	86.0	8.6	5.3
Ap2	19-37	0.1	0.8	8.0	33.9	43.1	85.9	8.7	5.4
A	37-62	0.1	1.0	11.5	42.8	36.7	92.1	5.6	2.4
Ab	62-104	0.0	1.1	13.0	45.3	34.7	94.1	5.0	0.9
Eb	104-146	0.1	1.2	12.7	46.0	35.2	95.1	2.4	2.5
Eb/Btb	146-173	0.1	1.2	12.5	47.6	34.0	95.4	4.2	0.4
Eb/Btb	173-200+	0.1	1.3	12.7	46.2	34.8	95.1	4.1	0.8
		Candler							
Ap1	0-29	0.0	0.9	14.0	65.4	16.5	96.8	1.4	1.8
Ap2	29-37	0.0	1.0	14.2	65.0	16.4	96.6	2.0	1.4
AE	37-72	0.0	0.7	13.6	70.0	12.6	97.0	0.8	2.2
E1	72-122	0.0	0.9	14.5	71.3	10.5	97.2	0.8	2.0
E2	122-182	0.0	0.6	13.0	72.0	12.4	98.0	1.1	0.9
E/Bt	182-200+	0.0	0.3	10.9	78.2	8.3	97.8	0.4	1.8
1801	200-254	0.0	0.7	15.9	75.2	6.5	98.2	0.5	1.3
1802	300-363	0.0	0.9	17.2	60.9	4.3	83.3	7.3	9.4

Samples taken greater than 2 m below the surface were given a numeric code.
* VC=very coarse sand; C=coarse sand; M=medium sand; F=fine sand; and VFS=very fine sand; and -=no data.

sand was greater than the VFS below a depth of 122 cm in the Candler soil. Pedon 12,0 was dominantly VFS to a depth of 156 cm and then FS was the dominant fraction to 402 cm. Soil horizons that were thought to have formed by local movement of sediments were higher in VFS than other soil horizons, i.e., pedon 12,0 and pedon 14,10.

Silt contents ranged from 0.4 to 8.7%. The silt contents of the A, E, Bt1, and Bt2 horizons of the Otela, Bushnell, and Shadeville soils were less than 3.5%. Silt contents though, increased to approximately 5 to 7% in the Bt3 horizon of the Otela soil and the 2Bt horizons in the Bushnell and Shadeville soils. Pedon 14,10 had the highest silt content of any soil in the QP. The silts were highest in the Ap horizons of this soil. The amount of silt decreased irregularly with depth in pedon 12,0.

Clay contents ranged from approximately 1 to 50%. Clay contents in the A and E horizons were normally less than 3%, but ranged to more than 5% in pedon 14,10. The clay contents of the Bt horizons of the Otela, Pedro, and Shadeville soils ranged from 15 to 20%. The Bt3 horizon of the Otela soil and the 2Bt horizons of the Bushnell and Shadeville soils were more than 30% clay.

Total phosphorus and OC contents, and pH in water, $CaCl_2$, and KCl are given in Table 4-4. Extractable bases and acidity, CEC, and BS are given in Table 4-5.

Table 4-4. Selected chemical data for the soils studied at the Quincey plot.

Horizon#	Depth (cm)	pH H_2O (1:1)	pH $CaCl_2$ (1:1)	pH KCL (1:1)	*EC dS/m	TP ug/g	OC g/Kg
		Otela					
Ap1	0-18	5.6	5.0	4.6	0.03	378	9.0
Ap2	18-36	5.7	4.9	4.6	0.02	447	7.2
AE	36-59	5.7	5.1	4.6	0.01	383	3.4
E1	59-88	5.6	5.0	4.7	0.01	308	1.5
E2	88-119	5.6	5.1	4.8	0.01	221	0.8
E3	119-138	5.6	5.0	4.8	0.01	165	0.3
Bt1	138-153	5.2	4.5	4.2	0.02	455	0.7
Bt2	153-193	5.2	4.5	4.2	0.02	398	0.6
Bt3	193-200+	5.4	4.5	4.3	0.01	10440	1.5
1601	279-305	5.3	4.7	4.5	0.02	33744	1.0
		Shadeville					
Ap1	0-16	6.2	5.6	5.0	0.03	345	4.9
Ap2	16-28	6.1	5.5	5.1	0.03	335	7.5
E1	28-51	6.0	5.2	4.8	0.01	319	1.9
E2	51-74	5.9	5.2	4.9	0.01	192	1.1
Bt1	74-112	5.5	4.6	4.4	0.01	556	1.5
Bt2	112-145	5.4	4.5	4.3	0.02	520	0.7
2Bt3	145-183	6.3	5.8	5.3	0.02	12395	1.2
2Bt4	183-194	7.7	6.9	6.1	0.09	17856	1.7
3R	194+	-	-	-	-	-	-
		Pedro					
Ap	0-18	5.7	5.3	4.9	0.07	1155	10.2
E	18-38	6.0	5.4	5.1	0.03	1284	3.9
Bt	38-49	5.6	4.8	4.5	0.02	3417	2.0
2C	49-200+	6.1	5.2	5.1	0.03	43185	2.3
		Bushnell					
Ap1	0-19	5.7	4.9	4.4	0.03	1218	8.0
Ap2	19-34	5.5	4.8	4.4	0.04	1236	8.1
2Bt1	34-69	6.8	6.3	6.0	0.03	21565	4.1
2Bt2	69-96	7.9	7.2	6.8	0.12	27117	3.2
3Cr	96-126	-	-	-	-	-	-
3R	126+	-	-	-	-	-	-

Table 4-4--continued.

Horizon#	Depth (cm)	pH H_2O	pH $CaCl_2$ (1:1)	pH KCL	*EC dS/m	TP ug/g	OC g/Kg
				Pedon 12,0			
Ap1	0-18	5.9	4.9	4.4	0.02	293	5.0
Ap2	18-37	5.7	5.4	4.8	0.04	371	7.5
C1	37-64	5.6	4.9	4.7	0.02	212	2.0
C2	64-85	5.1	4.8	4.7	0.03	169	1.1
C3	85-106	5.1	4.7	4.7	0.03	160	1.0
C4/Ab	106-112	4.9	4.5	4.5	0.03	240	1.0
Ab1	112-119	4.9	4.4	4.3	0.05	579	1.2
Ab2	119-137	5.2	4.4	4.2	0.02	593	1.2
C'1	137-149	5.3	4.4	4.3	0.01	259	0.5
C'2	149-156	5.4	4.4	4.4	0.01	221	0.3
C'3	156-200+	5.2	4.5	4.5	0.01	63	0.1
1201	253-303	5.2	4.5	4.3	0.02	358	0.6
1202	303-342	5.2	4.6	4.3	0.02	1112	0.5
1203	342-373	5.4	4.7	4.3	0.02	5091	0.8
1204	373-402	5.7	4.9	4.7	0.02	29557	1.1
				Pedon 14,10			
Ap1	0-19	5.1	4.7	4.4	0.09	1787	16.8
Ap2	19-37	5.1	4.7	4.3	0.06	1651	19.8
A	37-62	5.3	4.9	4.6	0.03	900	7.9
Ab	62-104	5.8	5.0	4.9	0.01	578	3.4
Eb	104-146	5.9	5.2	5.0	0.01	538	1.0
Eb/Btb	146-173	6.0	5.3	5.2	0.01	637	1.0
Eb/Btb	173-200+	6.1	5.4	5.3	0.01	743	0.6
				Candler			
Ap1	0-29	5.6	4.3	4.1	0.04	577	4.9
Ap2	29-37	5.4	4.8	4.5	0.04	598	7.5
AE	37-72	5.6	4.7	4.5	0.01	628	2.0
E1	72-122	5.6	4.9	4.6	0.01	557	1.5
E2	122-182	5.7	4.9	4.8	0.01	434	0.8
E/Bt	182-200+	5.5	4.5	4.6	0.01	539	0.5
1801	200-254	6.1	4.8	5.0	0.01	375	0.5
1802	300-363	5.4	5.3	4.7	0.02	1143	0.4

Samples taken greater than 2 m below the surface were given a numeric code.
* EC=electrical conductivity; TP=total phosphorous; OC=organic carbon; and -=no data.

Table 4-5. Selected chemical properties by horizon for the soils studied at the Quincey plot.

Horizon#	Depth (cm)	---Extractable bases-- Ca	Mg	K	Na	*SB	EA	CEC	BS
		------------cmol/Kg soil-------------							%
		Otela							
Ap1	0-18	0.99	0.23	0.06	0.02	1.3	5.2	6.5	20.2
Ap2	18-36	0.99	0.07	0.04	0.02	1.1	4.7	5.8	19.4
AE	36-59	0.46	0.02	0.02	0.01	0.5	3.5	4.0	12.9
E1	59-88	0.20	0.03	0.01	0.01	0.3	2.9	3.2	7.9
E2	88-119	0.27	0.06	0.01	0.02	0.4	2.7	3.1	11.6
E3	119-138	0.15	0.03	0.00	0.01	0.2	2.2	2.4	8.0
Bt1	138-153	2.55	0.74	0.04	0.03	3.4	4.8	8.2	40.9
Bt2	153-193	2.64	0.66	0.04	0.03	3.4	4.9	8.3	40.8
Bt3	193-200+	6.50	1.40	0.08	0.06	8.0	9.5	17.5	46.0
1601	279-305	12.07	2.58	0.34	0.08	15.1	12.8	27.9	53.9
		Shadeville							
Ap1	0-16	0.87	0.21	0.11	0.02	1.2	4.5	5.7	21.6
Ap2	16-28	1.16	0.37	0.10	0.02	1.7	4.1	5.8	28.5
E1	28-51	3.63	0.02	0.05	0.02	3.7	3.8	7.5	49.7
E2	51-74	3.09	0.02	0.04	0.02	3.2	0.4	3.6	86 8
Bt1	74-112	3.27	0.59	0.08	0.03	4.0	3.8	7.8	50.9
Bt2	112-145	3.59	0.44	0.06	0.04	4.1	2.4	6.5	63.3
2Bt3	145-183	13.27	0.66	0.09	0.08	14.1	4.4	18.5	76.2
2Bt4	183-194	31.78	0.81	0.22	0.12	32.9	5.2	38.1	86.3
3R	194+	-	-	-	-	-	-	-	-
		Pedro							
Ap	0-18	1.25	0.37	0.08	0.02	1.7	1.9	3.7	47.1
E	18-38	0.96	0.10	0.05	0.02	1.1	1.3	2.4	47.3
Bt	38-49	4.66	0.44	0.06	0.04	5.2	4.5	9.7	53.7
2C	49-200+	8.34	0.66	0.06	0.09	9.2	4.7	13.9	66.0
		Bushnell							
Ap1	0-19	0.79	0.19	0.07	0.02	1.1	2.8	3.9	27.5
Ap2	19-34	0.73	0.19	0.07	0.02	1.0	2.3	3.3	31.3
2Bt1	34-69	13.67	0.59	0.11	0.06	14.4	4.3	18.7	77.3
2Bt2	69-96	24.13	0.22	0.13	0.07	24.6	5.1	29.7	82.7
3Cr	96-126	-	-	-	-	-	-	-	-
3R	126+	-	-	-	-	-	-	-	-

Table 4-5--continued.

Horizon#	Depth (cm)	Ca	Mg	K	Na	*SB	EA	CEC	BS
		---Extractable bases--							
		cmol/Kg soil							%
		Pedon 12,0							
Ap1	0-18	0.23	0.09	0.06	0.02	0.4	1.6	2.0	19.8
Ap2	18-37	1.02	0.29	0.08	0.02	1.4	1.4	2.8	50.0
C1	37-64	0.11	0.02	0.04	0.01	0.2	2.0	2.2	7.8
C2	64-85	0.09	0.02	0.04	0.01	0.2	0	0.2	100.0
C3	85-106	0.21	0.02	0.04	0.02	0.3	0.3	0.6	47.4
C4/Ab	106-112	0.46	0.04	0.05	0.02	0.6	1.1	1.7	33.5
Ab1	112-119	2.51	0.37	0.21	0.03	3.1	3.2	6.3	49.2
Ab2	119-137	2.51	0.81	0.29	0.04	3.7	4.2	7.9	46.0
C'1	137-149	0.99	0.37	0.11	0.02	1.5	1.8	3.3	45.3
C'2	149-156	0.69	0.27	0.06	0.02	1.0	1.5	2.5	42.3
C'3	156-200+	0.23	0.11	0.02	0.02	0.4	0.2	0.6	58.4
1201	253-303	2.02	0.59	0.05	0.02	2.7	1.4	4.1	64.8
1202	303-342	4.39	0.81	0.05	0.03	5.3	1.5	6.8	78.3
1203	342-373	7.94	1.11	0.06	0.04	9.1	3.7	12.8	71.4
1204	373-402	9.25	1.18	0.09	0.06	10.6	4.8	15.4	68.9
		Pedon 14,10							
Ap1	0-19	2.15	0.44	0.20	0.05	2.8	5.5	8.3	34.1
Ap2	19-37	2.51	0.09	0.09	0.02	2.7	5.5	8.2	33.3
A	37-62	1.57	0.02	0.02	0.02	1.6	2.2	3.8	42.7
Ab	62-104	0.95	0.04	0.01	0.01	1.0	0.6	1.6	61.8
Eb	104-146	0.42	0.04	0.01	0.01	0.5	0.4	0.9	55.0
Eb/Btb	146-173	0.35	0.02	0.00	0.01	0.4	0.0	0.4	100.0
Eb/Btb	173-200+	0.28	0.05	0.00	0.02	0.3	0.0	0.3	100.0
		Candler							
Ap1	0-29	0.23	0.09	0.08	0.02	0.4	0.8	1.2	33.2
Ap2	29-37	0.61	0.26	0.10	0.02	1.0	1.0	2.0	49.1
AE	37-72	0.10	0.06	0.04	0.02	0.2	1.0	1.2	18.2
E1	72-122	0.03	0.01	0.03	0.01	0.1	0.4	0.5	14.4
E2	122-182	0.03	0.01	0.01	0.01	0.1	0.0	0.1	100.0
E/Bt	182-200+	0.03	0.01	0.01	0.01	0.1	0.0	0.1	100.0
1801	200-254	0.10	0.02	0.01	0.01	0.1	0.1	0.2	78.2
1802	300-363	0.73	0.29	0.04	0.02	1.1	0.4	1.5	72.0

Samples taken greater than 2 m below the surface were given a numeric code.
* SB=sum of bases; EA=extractable acidity; CEC=cation exchange capacity;and BS=base saturation; and -=no data.

Total phosphorus contents ranged from 63 to 43,185 ug/g. Total phosphorus contents were less than 1300 ug/g in most A, E, C, and Bt horizons. The TP contents were greater than 10,000 ug/g in the Bt3 horizon and sample 1601 of the Otela soil; 2C horizon in the Pedro soil; and 2Bt horizons of the Bushnell and Shadeville soils.

Base saturation was greater than 35% in all Bt horizons of the soils sampled. Horizons with textures of FS exhibited extreme variations in BS. The CEC ranged from less than 1 to 38 cmol/Kg soil.

Soil Mineralogy

Qualitative mineralogy and integrated peak intensities of the coarse clay fractions are presented in Table 4-6. Kaolinite (0.72-nm peak), hydroxy-interlayered vermiculite (HIV) (1.4-nm peak), and quartz (0.33-nm peak) were the dominant coarse clay minerals in the A, E, C, and Bt horizons. Smectite (1.8-nm peak), kaolinite, apatite (0.81-nm and 0.28-nm), and crandallite (0.57-nm and 0.29-nm) were dominant in the 2Bt, 3Cr, and 2C horizons. Hydroxy-interlayered vermiculite was identified by (a) a 1.4-nm (d001) peak at room temperature using a glycerol, Mg-saturated sample and (b) failure of the 1.4-nm peak to shift completely to 1.0-nm using incremental heat treatments (110^{o} and $300^{o}C$) and K-saturation. These steps distinguished HIV from both vermiculite and chlorite. No chlorite occurred in the soils sampled. Smectite was identified by (a) a

Table 4-6. Qualitative mineralogy and integrated peak intensities of the coarse clay fraction for the soils sampled at the Quincey plot.

Horizon@	Depth (cm)	*SM	HIV	KAO	QZ	CRAN	APA
		----(intergrated peak intensities)----					
		-----------------Otela------------------					
Ap1	0-18	+	# 67	154	86	-	-
Ap2	18-36	-	100	278	55	-	-
AE	36-59	-	245	158	909	-	-
E1	59-88	-	135	60	311	-	-
E2	88-119	-	123	57	353	-	-
E3	119-138	-	61	23	300	-	-
Bt1	138-153	-	382	1473	405	-	-
Bt2	153-193	-	149	2314	197	-	-
Bt3	193-200	+	tr	371	51	+	-
1601	279-305	+	-	215	42	+	+
		-----------------Shadeville-------------					
Ap1	0-16	+	320	181	914	-	-
Ap2	16-28	-	49	39	235	-	-
E1	28-51	-	66	46	271	-	-
E2	51-74	+	53	59	236	-	-
Bt1	74-112	+	82	408	173	-	-
Bt2	112-145	-	69	609	161	+	-
2Bt3	145-183	+	-	115	34	+	+
2Bt4	183-194	+	-	17	17	+	+
		-----------------Pedro------------------					
Ap	0-18	+	67	71	189	+	-
E	18-38	+	55	71	175	+	-
Bt	38-49	-	151	1125	145	+	-
2C	49-200	-	tr	581	-	+	+
		-----------------Bushnell---------------					
Ap1	0-19	-	300	170	518	+	-
Ap2	19-34	+	185	456	225	+	-
2Bt1	34-69	+	45	315	38	+	+
2Bt2	69-96	+	-	111	-	-	+

Table 4-6--continued.

Horizon@	Depth (cm)	*SM	HIV	KAO	QZ	CRAN	APA
		----(intergrated peak intensities)----					
		----------------Pedon 12,0--------------					
Ap1	0-18	-	65	9	284	-	-
Ap2	18-37	-	69	14	271	-	-
C1	37-64	-	71	10	314	-	-
C2	64-85	-	346	50	1008	-	-
C3	85-106	-	369	96	985	-	-
C4/Ab	106-112	-	80	20	220	-	-
Ab1	112-119	-	86	34	214	-	-
Ab2	119-137	-	77	39	221	-	-
C'1	137-149	-	70	45	174	-	-
C'2	149-156	-	311	151	335	-	-
C'3	156-200	-	84	75	116	-	-
1201	253-303	-	118	1241	336	-	-
1202	303-342	+	-	1000	285	-	-
1203	342-373	+	-	400	166	+	+
1204	373-402	+	-	177	70	+	+
		----------------Pedon 14,10-------------					
Ap1	0-19	+	36	39	136	+	-
Ap2	19-37	+	42	32	172	+	-
A	37-62	-	114	92	108	-	-
Ab	62-104	-	111	82	169	-	-
Eb	104-146	-	313	117	1107	-	-
Eb/Btb	146-173	-	63	34	305	-	-
Eb/Btb	173-200	-	137	8	1501	-	-
		----------------Candler----------------					
Ap1	0-29	+	65	149	182	-	-
Ap2	29-37	-	58	131	186	-	-
AE	37-72	-	447	889	714	-	-
E1	72-122	-	383	827	623	-	-
E2	122-182	-	409	925	632	-	-
E/Bt	182-200	-	150	352	266	-	-
1801	200-254	-	77	2166	213	-	-
1802	300-363	-	48	1659	45	-	-

@ Samples taken greater than 2 m below the surface were given a numeric code.
* SM=Smectite; HIV=Hydroxy-interlayered vermiculite; KAO=Kaolinite; QZ=Quartz; CRAN=Crandallite; APA=Apatite; #=intergrated peak intensities ;tr=Trace amounts; +=present; and -=non-detectable.

broading of the 1.4-nm peak to approximately 1.8-nm using a glycerol, Mg-saturated sample and (b) collapse of this broad peak to approximately 1.2-nm to 1.0-nm using K-saturation and heat treatments to 110^{o}C. Examples of XRD patterns for the coarse clay fractions are presented in Figs. 3-11 to 3-12, and Fig. 4-1.

Kaolinite, HIV, and quartz were the dominant coarse-clay minerals in the A, E, Bt, and C horizons. Quartz and HIV were most abundant in the A and E horizons but decreased in abundance with depth. Kaolinite was the most abundant coarse clay mineral in the Bt horizons. Similar mineralogical trends have been reported in Florida soils by Cabrera-Martinez (1988), Cabrera-Martinez et al.(1989b), and Harris et al. (1988).

Kaolinite, smectite, apatite, and crandallite were the dominant coarse clay minerals in the 2Bt and 2C horizons. Crandallite also occurred in the A and E horizons of the Bushnell and Pedro soils.

The fine clay fractions for the soils studied were dominantly smectite and kaolinite. The x-ray diffraction patterns for the fine clay of the Bt1 horizon in the Otela soil is presented as an example of the fine clay diffraction patterns (Fig. 4-2).

The mineralogy of the silt fractions were also examined and are presented for selected horizons in the Candler and Shadeville soils (Table 4-7). Mineralogy of the silt

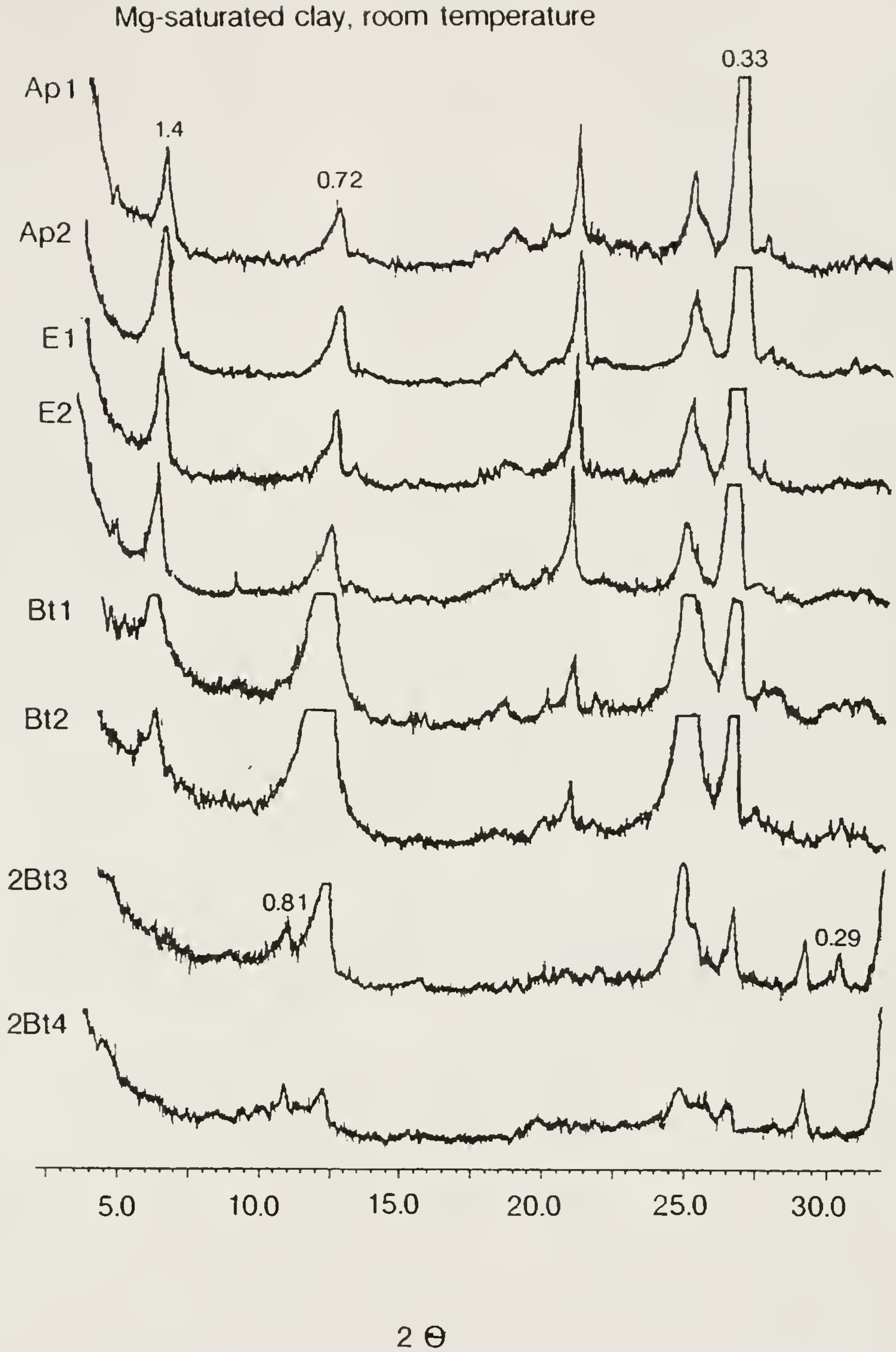


Figure 4-1. X-ray diffraction patterns of Mg-saturated, glycerol-solvated coarse clay by horizon for the Shadeville soil at the Quincey plot.

Figure 4-2. X-ray diffraction patterns of Mg- and K-saturated glycerol-solvated fine clay for the Bt1 horizon of the Otela soil at the Quincey plot.

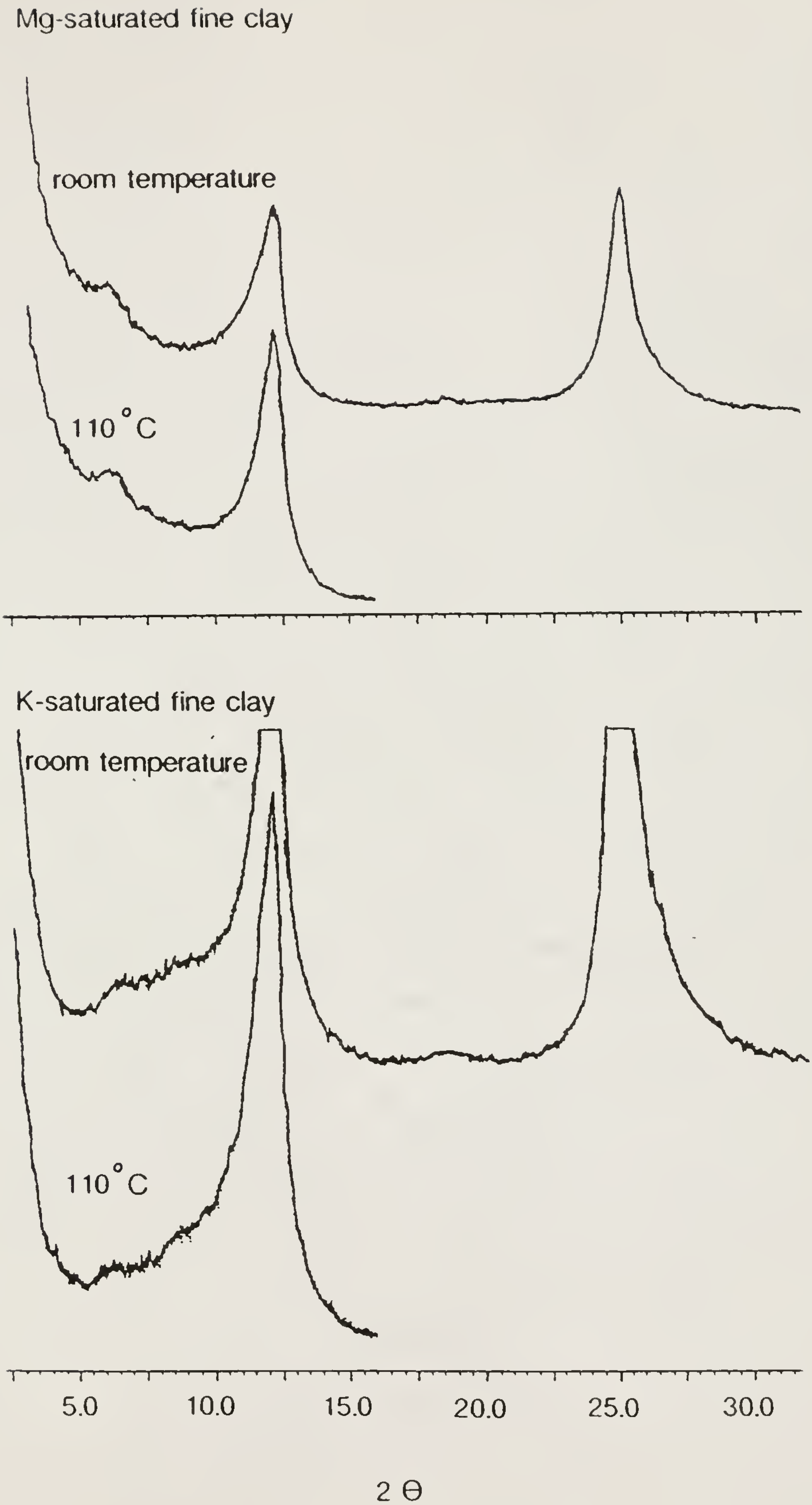

Mg-saturated fine clay
room temperature
110 °C
K-saturated fine clay
room temperature
110 °C
5.0
10.0
15.0
20.0
25.0
30.0
2 Θ

Table 4-7. Qualitative mineralogy of the silt fractions for selected horizons from the Candler and Shadeville soils at the Quincey plot.

Soil Horizon	Depth (cm)	Silt Fraction	Mineral			
			---------------Candler---------------			
Ap1	0-29	coarse	*QZ			
		medium	QZ	HIV(tr)		KAO(tr)
		fine	QZ	HIV		KAO
Ap2	29-37	coarse	QZ			
		medium	QZ	HIV(tr)		KAO(tr)
		fine	QZ	HIV		KAO
			--------------Shadeville-------------			
Bt1	74-112	coarse	QZ			
		medium	QZ			
		fine	QZ	HIV		KAO
Bt2	112-145	coarse	QZ			
		medium	QZ			
		fine	QZ	HIV		KAO
2Bt3	145-183	coarse	QZ	CRAN	APA	
		medium	QZ	CRAN	APA	
		fine	QZ	CRAN	APA	KAO
2Bt4	183-194	coarse	QZ	APA		
		medium	QZ	APA		
		fine	QZ	APA		

* QZ=Quartz; HIV=Hydroxy-interlayered vermiculite; KAO=Kaolinite; CRAN=Crandallite; APA=Apatite; and tr=Trace.

fraction was determined using slightly oriented wet mounts instead of dry powder mounts. The silt fractions in the Ap horizons of the Candler soil and the Bt1 and Bt2 horizons of the Shadeville soil were dominated by quartz, as were all silt fractions in all soils sampled. Trace amounts of HIV and kaolinite were detectable in the medium silt fractions with these minerals increasing slightly in the fine silt fractions. The mineralogy of these horizons were typical of the A, E, Bt, and C horizons of the soils sampled. Similar results have been reported for other Florida soils by Harris et al. (1988).

The silt fractions in the 2Bt horizons of the Shadeville soil were also dominated by quartz. Kaolinite was present in the fine silt fraction of the 2Bt3 horizon. Apatite and crandallite were present in all silt fractions in the 2Bt horizons, but crandallite was absent in the 2Bt4 horizon. The silt fractions of the 2Bt horizons in the Bushnell soil were also mostly quartz, apatite, and crandallite.

Fossil-Limestone Identification

Fossils from the 3Cr and 3R horizons of the Bushnell and Shadeville soils were identified as middle to late Eocene in age (Doug Jones, 1987, Personal communications). The fossils were correlated as constituents of the Ocala Group Limestones. Foraminifera (Operculinoides species), Bryozoa (Discoporella), Gastropoda, Echinoderms

(Neolaganuas), trace fossils (Subfodiodomicil ocalea), and Bivalves (Chlamys species) were some of the fossils identified in these horizons. These species were estimated to have lived in oceans that were less than 20 m deep.

Insoluble Limestone Residue

The percent insoluble residue of the limestone R horizons is presented in Table 4-8. The insoluble residues were less than 1.2% for the three horizons tested. The sand and silt contents of the insoluble residue were higher in the 3R horizon of the Shadeville soil and the clay contents were higher in the 3Cr and 3R horizons of the Bushnell soil.

The coarse clay mineralogy in the 3Cr horizon of the Bushnell soil was mostly apatite with trace amounts of smectite and kaolinite. The fine clay mineralogy was smectite and kaolinite. The coarse clay mineralogy of the 3R horizon was mostly apatite and quartz with trace amounts of smectite. The fine clay mineralogy was dominantly smectite with trace amounts of kaolinite. The mineralogy of the silt fractions of both the 3Cr and 3R horizons were apatite and quartz.

Apatite was the dominant mineral in the coarse clay fraction in the 3R horizon of the Shadeville soil. The mineralogy of the fine clay fraction was mostly smectite with trace amounts of kaolinite. The mineralogy of the silt fraction was apatite and quartz.

Table 4-8. Insoluble residues of the Ocala Group Limestones and particle-size data of the insoluble residues for R horizons in the Bushnell and Shadeville soils at the Quincey plot.

Soil	Horizon	Insoluble Residue	Sand	Silt	Clay
		----------------%	----------	----------	----------
Bushnell	3Cr	0.9	11.8	5.6	82.6
	3R	0.4	16.2	5.4	78.4
Shadeville	3R	1.1	23.5	12.2	64.3

Microscopy Study

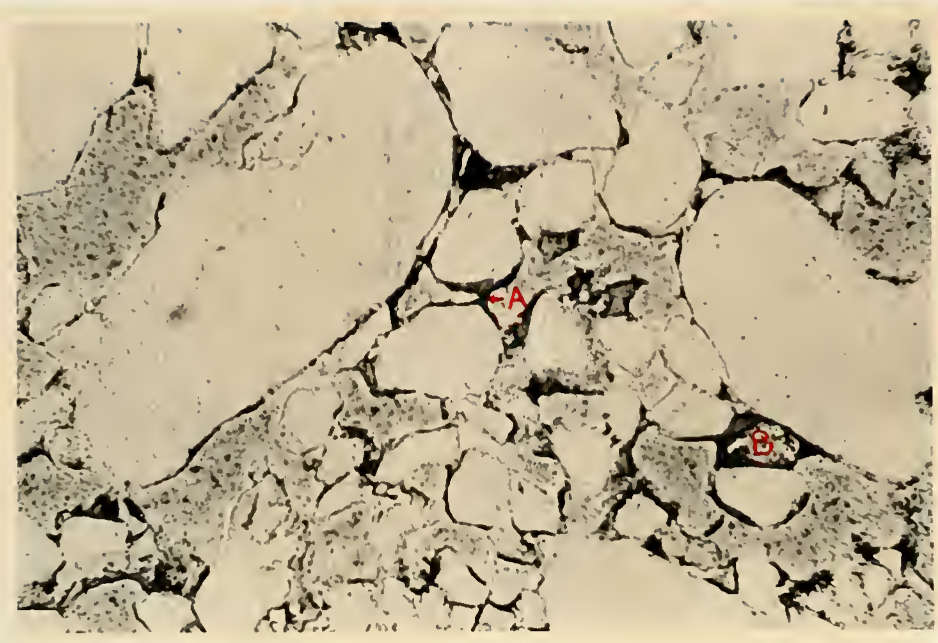
Thin sections

Clay bridging between sand grains and oriented clay in pores and on sand grains were observed in the Bt1 and Bt2 horizons in the Otela and Shadeville soils (Fig. 4-3a) and in the Bt horizon of the Pedro soil. Clay skins were not described during field observation of these soils.

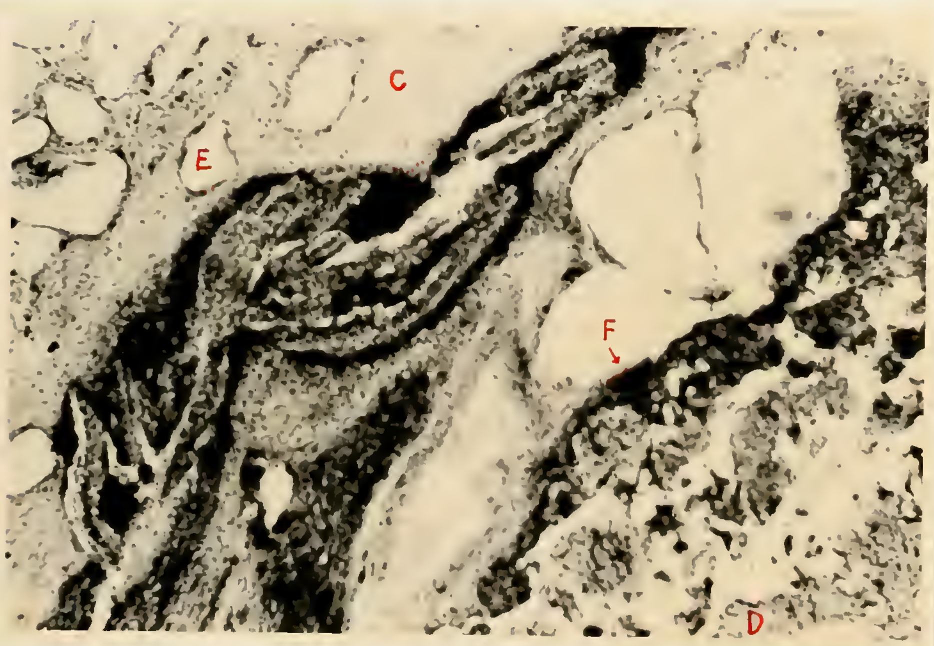
Wavellite was not identified in any horizons using XRD, but was observed in the Bt horizon of the Pedro soil in thin sections. Needles of wavellite were growing in sand-sized grains of another phosphatic mineral, probably crandallite or apatite. Oriented clays coated the phosphatic grains and were probably supplying aluminum for the formation of wavellite. Wavellite was not observed below the Bt horizon, in the 2C horizon, or in any other horizon that was sampled.

The contact between the 2Bt2 horizon and the 3Cr horizon in the Bushnell soil is shown in Fig. 4-3b. The 3Cr horizon was composed of finely-divided carbonates and fossils. The contact between these two horizons was abrupt, wavy. The 3Cr horizon did not contain any visible amounts of clay or quartz, but both were abundant in the overlying 2Bt2 horizon. The clay immediately in contact with the 3Cr horizon exhibited an orientation parallel with the surface of the limestone and had a few quartz grains imbedded in the clay matrix. Above this zone, the 2Bt2 horizon was composed

Figure 4-3. Thin sections of selected horizons of the Otela and Bushnell soils at the Quincey plot.
a) Thin section of E and Bt horizon boundary in the Otela soil showing clay bridging (A), and oriented clay in pores (B), using polarized light.
b) Thin section of 2Bt2 (C) and 3R (D) horizon boundary in the Bushnell soil showing quartz grains (E) embedded in the 2Bt2 horizon and the abrupt boundary (F) between the horizons, using polarized light.



a.



b.

of a matrix of clay imbedded with quartz and phosphatic grains. This slightly oriented clay zone was observed during field observations in both the Bushnell and Shadeville soils. These clayey zones were variable in thickness (normally less than 5 cm) and did not form a continuous layer above the 3R horizons. Apatite, smectite, and kaolinite were the dominant clay minerals in these layers.

Fine stratifications were observed in the Ab horizon (115 cm) of pedon 12,0. The stratifications were composed of alternating bands of quartz sand and quartz sand plus clay. Pockets of an opaque black substance (probably organic matter) was mixed in with the stratifications.

Heavy minerals

The percent heavy minerals recovered from the VFS fractions are presented in Table 4-10. Complete quantification of the heavy mineral suite in each soil horizon was not determined because of the results reported by Carlisle (1962) and Cabrera-Martinez (1988) who indicated very little change in kind or quanity of heavy minerals with depth. Rutile, tourmaline, zircon, kyanite, and assorted opaque grains were the dominant heavy minerals in all soil horizons. Apatite was the dominant heavy mineral in the 2Bt horizons. Epidote and garnet were not observed in the 2Bt horizons. Epidote and garnet have been correlated with the Hawthorn formation by Pirkle et al. (1965), Pirkle et al.

(1985), and Scott (1983). However, Scott (1983) suggested that epidote and garnet may be absent in reworked Hawthorn sediments.

Sand-grain analysis

Sand grains were analyzed using a dissecting microscope. Sand grains were subangular to rounded in shape and ranged from low to high sphericity in shape (Folk, 1980). Some grains were angular. Grains ranged from frosted to clear, with most of the frosted grains being rounded with high sphericity. Some grains were pitted and/or had small irregular cracks. Both surface features were sometimes filled with minute amounts of clay.

Grains counts were performed on the fine-sand fractions of selected horizons. The results of the grain counts are given in Table 4-9. "Other" grains, as given in Table 4-9, were defined as grains that were phosphatic and/or silicified. Most of the "other" grains in the Ap and E horizons were silicified. The percentage of phosphatic grains were greatest in the 2Bt horizons.

Uniformity of Parent Materials

Soil stratigraphy

Stratigraphy is normally associated with geology. Stratigraphy deals with the origin, composition, arrangement, and chronologic correlation of rock strata (Bates and Jackson, 1984). Geomorphologist use lateral variations of defined strata to explain landscape evolution.

Table 4-9. Petrographic analysis of the fine-sand fraction of selected soils and horizons at the Quincey plot.

Soil	Horizon	Quartz --%--	*"Other"
Shadeville	Ap1	99	tr
	Ap2	100	ND
	AE	99	tr
	E1	99	tr
	E2	99	tr
	Bt1	99	tr
	Bt2	98	2
	2Bt3	78	22
	2Bt4	83	17
Pedro	Ap	99	1
	E	99	1
	Bt	95	5
	2C	80	20
Bushnell	Ap1	99	1
	Ap2	99	1
	2Bt1	91	9
	2Bt2	76	24
Candler	Ap1	100	ND
	Ap2	100	ND
	E1	100	ND

* "Other"=Phosphatic and silicified grains; tr=trace amounts; and ND=non-detected.

The methods of stratigraphy were applied to soils by Butler (1959), Robertson-Rintoul, (1986), and Washer and Collins (1988). If soil horizons are used as stratigraphic markers and the processes of pedogenesis are assumed to have had minimum influence, then the principle of random association as defined by Butler (1959) can be used to recognize discontinuities in the soils of a defined physiographic area. The principle is based on the idea that two commonly associated layers represent different deposits if, in at least one place, they are separated.

The principle of random association was tested on the soils of the CLP. Extreme caution was used in interpreting the data due to the non-stable nature of the landscapes, i.e., karst. Descriptions were made for the soils on the nearly level landscapes of the CLP to a depth of 2 m or limestone, whichever was shallower. Seventy-nine soil profile descriptions were written by 10 different soil scientist over a 2-year period. The descriptions were reduced to 12 observed vertical sequences of soil strata based on texture and color.

The 12 vertical sequences of soil strata are presented in Fig. 4-4. The number of strata in a sequence ranged from 1 to 4. Sequences 1 and 2 were representative of homogeneous strata. Sequence 1 was FS and sequence 2 was FS with lamellae. These sequences represented (a) deep deposits of FS, i.e., old dunes, (b) paleo-karst features

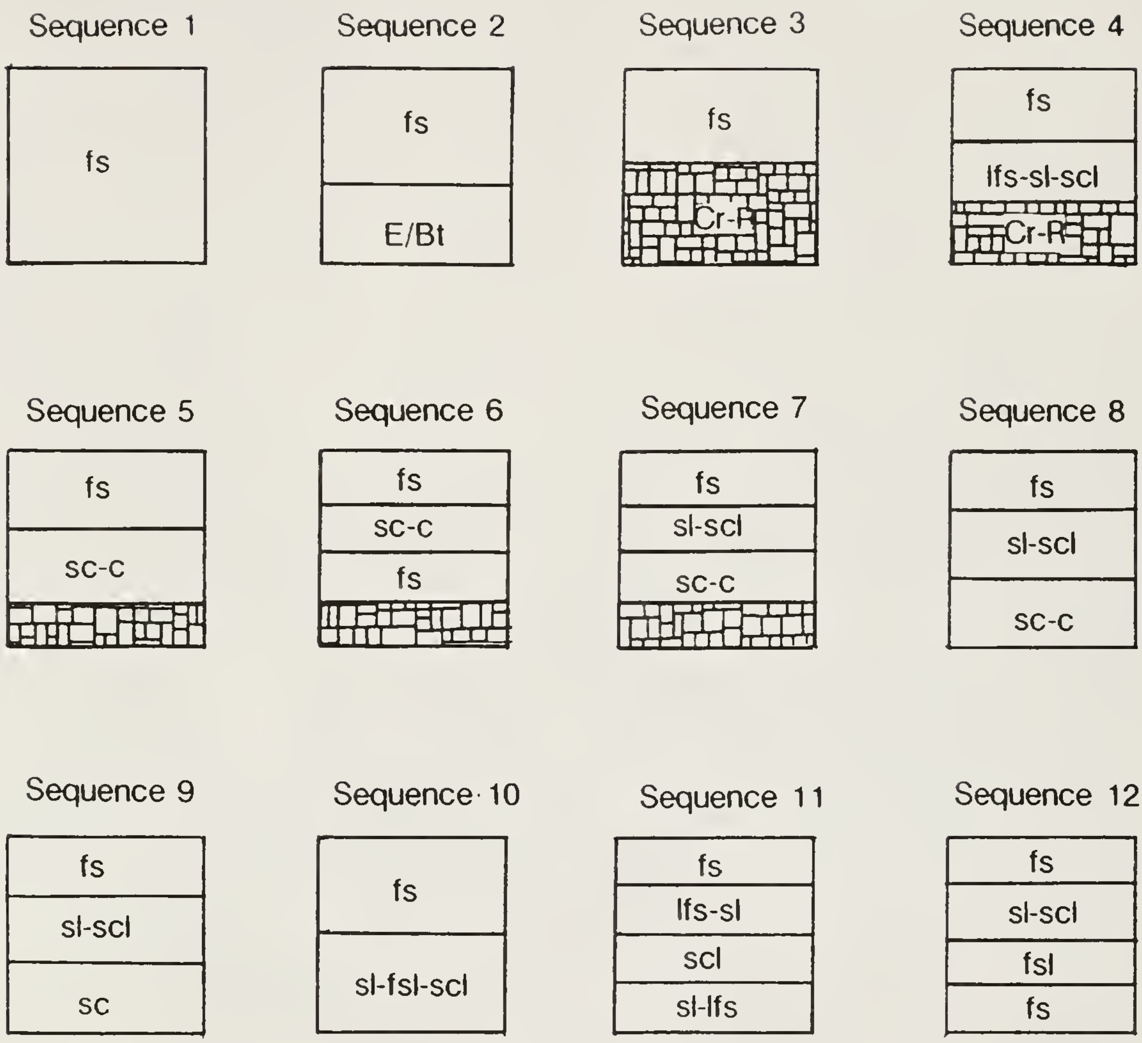


Figure 4-4. Dominant vertical sequences of soil strata occurring on the Chiefland Limestone Plain. (fs=fine sand; E/Bt=fine sand horizon with lamellae; Cr-R=limestone; lfs=loamy fine sand; sl=sandy loam; fsl=fine sandy loam; scl=sandy clay loam; sc=sandy clay; c=clay).

that had been filled, and (c) lateral variations in E horizon thickness above underlying Bt horizons.

Sequence 3 was representative of a FS strata overlying limestone at various depths. Sequence 3 occurred in some nearly level areas (slopes < 2%) that were greater than 50 ha in size. Also occurring in these areas were sequences 4,5,6,7, and 8. Comparing sequences 3,4,5,6,7, and 8, a conclusion could be drawn that the FS strata was not related to any of the other strata since, (a) loamy and clayey strata separated the FS and Cr-R strata in many places and (b) the FS occurred over the Cr-R strata without the loamy or clayey strata. Vernon (1951) reported that the Ocala Group Limestones were > 95% calcium carbonate. Weathering of these limestones would probably not yield the strata overlying them. However, lateral variations in limestone purity, i.e., "dirty limestones", could not be discounted on the CLP (R.C. Lindquist, 1986, personal communications). Therefore, residual soil strata with textures of loamy fine sand, sandy loam, and sandy clay loam might be possible upon weathering of "dirty limestones".

The conclusions based on the principle of random association must be substantiated by physical and chemical data. The sandy clay and clay strata of sequences 5, 6, and 8 were grayer in color and higher in TP than sequences 4 and 7. The Ocala Group Limestones are low in TP and clay residues and could not form these clayey strata upon

weathering. Sequence 6 provided more evidence that sequences 5 and 8 were not related to the limestones, since a FS strata separated the two.

Clay content increased with depth in sequences 9 and 10. The sandy clay strata in sequence 9 was grayer and higher in TP then the sandy clay loam to sandy clay strata in sequence 10.

Sequences 11 and 12 provided evidence that the loamy fine sand, sandy loam, and sandy clay loam strata (LFS-SL-SCL) were not related to the Cr-R or sandy clay and clay strata. The LFS-SL-SCL strata of sequences 11 and 12 were underlain by FS strata, which separated them from all other strata.

Three conclusions could be made concerning the uniformity of soils on the CLP using the principle of random association: (a) the sandy clay and clay strata in sequences 5, 6, 7, 8, and 9 were not related to the Ocala Group Limestones, (b) the LFS-SL-SCL strata of sequences 11 and 12 were not related to the sandy clay and clay strata of sequences 5, 6, 8, and 9, and (c) the LFS-SL-SCL strata of sequences 11 and 12 were not related to the Ocala Group Limestones.

<u>Stationary soil components</u>

Sand-sized particles are normally regarded as non-mobile or stationary soil components in Florida soils (Carlisle, 1962; Washer and Collins, 1988; Cabrera-Martinez,

1988; Cabrera-Martinez et al., 1989a). Quartz was found to be the dominant sand-size mineral in the QP soils. Sand-sized quartz particles are relatively resistant to weathering (Wilding et al., 1982).

Percent total heavy minerals have been used as stationary components in studying Florida soils (Carlisle, 1962; Cabrera-Martinez, 1988; Cabrera-Martinez et al., 1989a) and geologic formations (Pirkle et al., 1965; Pirkle and Yoho, 1970; Pirkle et al., 1985; Eichenholtz et al., 1989; Pirkle et al., 1989).

The ratio's of MS/TS (MSTS), FS/TS (FSTS), VFS/TS (VFSTS), FS+VFS (FSVFS) on a clay free basis, % coarse fragments, and % heavy minerals (HM) are presented in Table 4-10. Multiple ratio's are presented so that trends can be established in each soil based on more than 1 or 2 stationary components (Wang and Arnold, 1973).

Inflections in FSTS, VFSTS, FSVFS, and HM depth distributions occurred between the Bt2 and Bt3 horizons in the Otela soil. Inflections in MSTS, FSVFS, CF, and HM also indicated a discontinuity between the Bt3 horizon and sample 1601. No lithological discontinuities were described in the Otela soil during field observations.

The Shadeville soil had inflection in FSTS, VFSTS, FSVFS, CF, and HM between the Bt2 and 2Bt3 horizons. Percent coarse fragments and HM indicated a discontinuity between the 2Bt3 and 2Bt4 horizon. Two lithological

Table 4-10. Summary of selected stationary components by horizon for soils at the Quincey plot.

Horizon#	Mid-Depth (cm)	*MS -- TS	FS -- TS	VFS --- TS	FSVFS ----- TS	CF	HM
						----%----	
		-------------Otela---------------					
Ap1	9	.08	.49	.43	.89	0.1	0.9
Ap2	27	.09	.48	.41	.87	0.1	1.0
AE	48	.12	.47	.39	.84	0.3	1.6
E1	74	.13	.49	.37	.84	0.1	1.5
E2	104	.12	.47	.39	.85	0.2	1.5
E3	129	.12	.46	.41	.85	0.3	1.3
Bt1	145	.11	.42	.46	.86	0.0	0.4
Bt2	173	.15	.47	.47	.82	0.1	0.5
Bt3	197	.19	.56	.24	.73	0.7	1.9
1601	292	.27	.55	.17	.62	21.3	27.7
		-----------Shadeville------------					
Ap1	8	.13	.48	.38	.82	0.0	1.8
Ap2	22	.12	.48	.39	.86	0.1	1.8
E1	40	.11	.46	.41	.85	0.1	1.4
E2	63	.11	.45	.42	.85	0.0	1.2
Bt1	93	.10	.43	.46	.87	0.0	0.9
Bt2	129	.12	.46	.41	.85	0.0	0.8
2Bt3	164	.18	.56	.22	.71	18.5	6.9
2Bt4	189	.17	.51	.27	.66	0.6	0.9
		-------------Pedro---------------					
Ap	9	.14	.49	.35	.82	1.6	4.0
E	28	.13	.49	.35	.82	7.2	2.2
Bt	44	.16	.50	.31	.76	8.1	5.7
2C	125	.19	.50	.21	.62	38.8	27.8
		------------Bushnell-------------					
Ap1	9	.12	.50	.36	.84	1.5	1.2
Ap2	26	.12	.50	.36	.84	1.5	1.1
2Bt1	52	.17	.54	.26	.73	6.4	6.4
2Bt2	83	.19	.54	.21	.67	10.9	10.0

Table 4-10--continued.

Horizon#	Mid-Depth (cm)	*MS / TS	FS / TS	VFS / TS	FSVFS / TS	CF %	HM %
				Pedon 12,0			
Ap1	9	.11	.42	.45	.86	0.0	0.4
Ap2	27	.11	.43	.45	.86	0.0	0.6
C1	51	.10	.41	.48	.86	0.0	0.5
C2	75	.11	.41	.48	.85	0.0	0.4
C3	96	.10	.42	.47	.85	0.0	0.4
C4/Ab	109	.10	.42	.47	.80	0.1	0.5
Ab1	116	.10	.41	.48	.85	0.0	0.3
Ab2	128	.10	.39	.49	.91	0.0	0.3
C'1	143	.07	.36	.57	.91	0.0	0.3
C'2	152	.06	.34	.59	.83	0.0	0.2
C'3	178	.15	.74	.11	.83	0.0	0.3
1201	278	.12	.44	.42	.81	0.0	3.2
1202	323	.15	.54	.29	.80	0.1	10.8
1203	358	.17	.60	.20	.76	0.5	2.7
1204	404	.18	.54	.21	.68	85.5	4.6
				Pedon 14,10			
Ap1	9	.11	.42	.47	.80	0.6	0.3
Ap2	27	.09	.39	.50	.81	0.7	0.3
A	50	.12	.46	.39	.81	1.4	0.6
Ab	83	.14	.48	.37	.81	1.2	0.5
Eb	123	.13	.48	.37	.83	2.1	0.2
Eb/Btb	160	.13	.49	.36	.82	3.2	0.3
Eb/Btb	187	.13	.49	.37	.82	4.1	0.5
				Candler			
Ap1	15	.14	.68	.17	.83	0.2	1.4
Ap2	33	.15	.67	.17	.83	0.1	1.2
AE	55	.14	.72	.13	.84	0.1	1.5
E1	97	.15	.73	.11	.83	0.5	1.4
E2	152	.13	.73	.13	.85	0.5	1.5
E/Bt	191	.11	.79	.08	.88	0.1	3.5
1801	254	.16	.77	.07	.83	0.0	5.2
1802	363	.21	.73	.05	.72	0.0	4.0

Samples taken greater than 2 m below the surface were given a numeric code.
* MS=medium sand; FS=fine sand; VFS=very fine sand; FSVFS=fine sand + very fine sand; TS=total sand; CF=coarse fragments; HM=heavy minerals.

discontinuity were described during field observations in the Shadeville soil.

Inflections in VFSTS, FSVFS, CF, and HM indicated a discontinuity between the Bt and 2C horizons in the Pedro soil. One discontinuity was described during field observation of the Pedro soil.

The VFSTS, FSVFS, CF, and HM indicated a discontinuity between the Ap2 and 2Bt1 horizons in the Bushnell soil. Two discontinuities were described during field observations.

Depth distributions of MSTS, FSTS, and VFSTS indicated a discontinuity between the C'2 and C'3 horizons in Pedon 12,0. The FSTS, VFSTS, and HM indicated a discontinuities between the C'3 horizon and sample 1201 and sample 1201 and 1202. Samples taken below 200 cm in the soil appeared to be separate and distinct strata. Soil horizons below 106 cm were described as buried.

Pedon 14,10 was located in the bottom of a sinkhole and the FSTS, VFSTS, and CF indicated a discontinuity between the Ap2 and A horizons. Soil horizons below 62 cm were described as buried.

No lithological discontinuities were indicated in the Candler soil. The HM increased with depth below 182 cm and the FSVFS indicated a break between 1801 and 1802.

<u>Non-stationary soil components</u>

Fine clay (FC), coarse clay (CC), total clay (TC), FC/CC, and FC/TC ratio's are presented in Table 4-11. The

Table 4-11. Fine, coarse, and total clay by horizon for soils with Bt horizons at the Quincey plot.

Horizon#	Mid-Depth (cm)	*FC	CC	TC (%)	FC/CC	FC/TC
		---------Otela----------				
Ap1	9	0.8	0.8	1.6	1.0	0.5
Ap2	27	1.2	0.8	2.0	1.5	0.6
AE	48	1.0	0.7	1.7	1.5	0.6
E1	74	0.7	0.7	1.4	1.0	0.6
E2	104	0.5	0.7	1.2	0.7	0.4
E3	129	0.4	0.5	0.9	0.8	0.4
Bt1	145	12.5	3.2	15.7	3.9	0.8
Bt2	173	13.0	2.9	15.9	4.5	0.8
Bt3	197	25.6	8.1	33.7	3.2	0.8
1601	292	35.1	15.2	50.3	2.3	0.7
		-------Shadeville-------				
Ap1	8	0.7	0.8	1.5	0.9	0.5
Ap2	22	0.8	0.8	1.6	1.0	0.5
E1	40	1.0	0.8	1.8	1.3	0.6
E2	63	1.0	0.8	1.8	1.3	0.6
Bt1	93	12.5	2.9	15.3	4.3	0.8
Bt2	129	13.6	2.6	16.2	5.2	0.8
2Bt3	164	26.3	4.9	31.2	5.4	0.8
2Bt4	189	35.3	14.8	50.1	2.4	0.7
		----------Pedro---------				
Ap	9	1.2	1.1	2.3	1.1	0.5
E	28	1.2	1.2	2.4	1.0	0.5
Bt	44	14.3	5.6	19.9	2.6	0.7
		--------Bushnell--------				
Ap1	9	1.0	0.8	1.8	1.3	0.6
Ap2	26	1.3	0.8	2.1	1.6	0.6
2Bt1	52	28.5	9.0	37.5	3.2	0.8
2Bt2	83	31.6	11.2	42.8	2.8	0.7

Samples taken greater than 2 m below the surface were given a numeric code.
* FC=fine clay; CC=coarse clay; TC=total clay.

fine and coarse clay fractions were only determined for those soils with Bt horizons. The FC/CC ratio's were approximately 1 to 1.5 for the A and E horizons. The FC/CC ratio's ranged from 2.6 to 5.4 in the Bt horizons. The FC/CC ratio's decreased with depth below the Bt horizons in all soils. The FC/TC ratio's increased to maximum in the Bt horizons and then decreased. Since oriented clays were observed in thin sections and FC increased in the Bt horizons these horizons were classified as argillic horizons (Soil Survey Staff, 1975).

Based on the results of the stationary and non-stationary components, the A, E, and Bt horizons of the Otela, Shadeville, and Pedro soils were formed from the same parent material.

Parent Material-Time-Soil Sequence Model

Parent material-time model

A parent material-time model is presented in Table 4-12, and a generalized landscape evolution model is presented in Fig. 4-5. These models were based on field and laboratory evidence presented and the works of Vernon (1951), Pirkle (1956), Pirkle (1957), Pirkle et al., (1965), Puri et al., (1967), Williams et al., (1977), and Scott (1983).

The Eocene sediments were restricted to the Ocala Group Limestones (Table 4-12). The Miocene, Pliocene, and reworked Miocene-Pliocene sediments were clayey, gray in color, high in phosphatic minerals, and TP. Pleistocene

Table 4-12. Proposed parent material-time model for the soils on the Chiefland Limestone Plain.

Epoch	Parent Material: Sediments	Parent Material: Properties
Eocene	limestone	- > 95% calcium carbonate
Miocene to Pliocene	sandy clay loam sandy clay clay	-colors are gray -clay contents > 35% -total phosphorous contents > 10,000 ug/g -phosphate minerals present
Pleistocene	fine sand loamy fine sand sandy loam sandy clay loam	-colors range from white (10YR 8/1) to brownish yellow (10YR 6/8) -clay contents < 35% -total phosphorus contents < 3000 ug/g
Holocene	+	+

+ Holocene parent materials are normally fine sands but include any recently reworked materials.

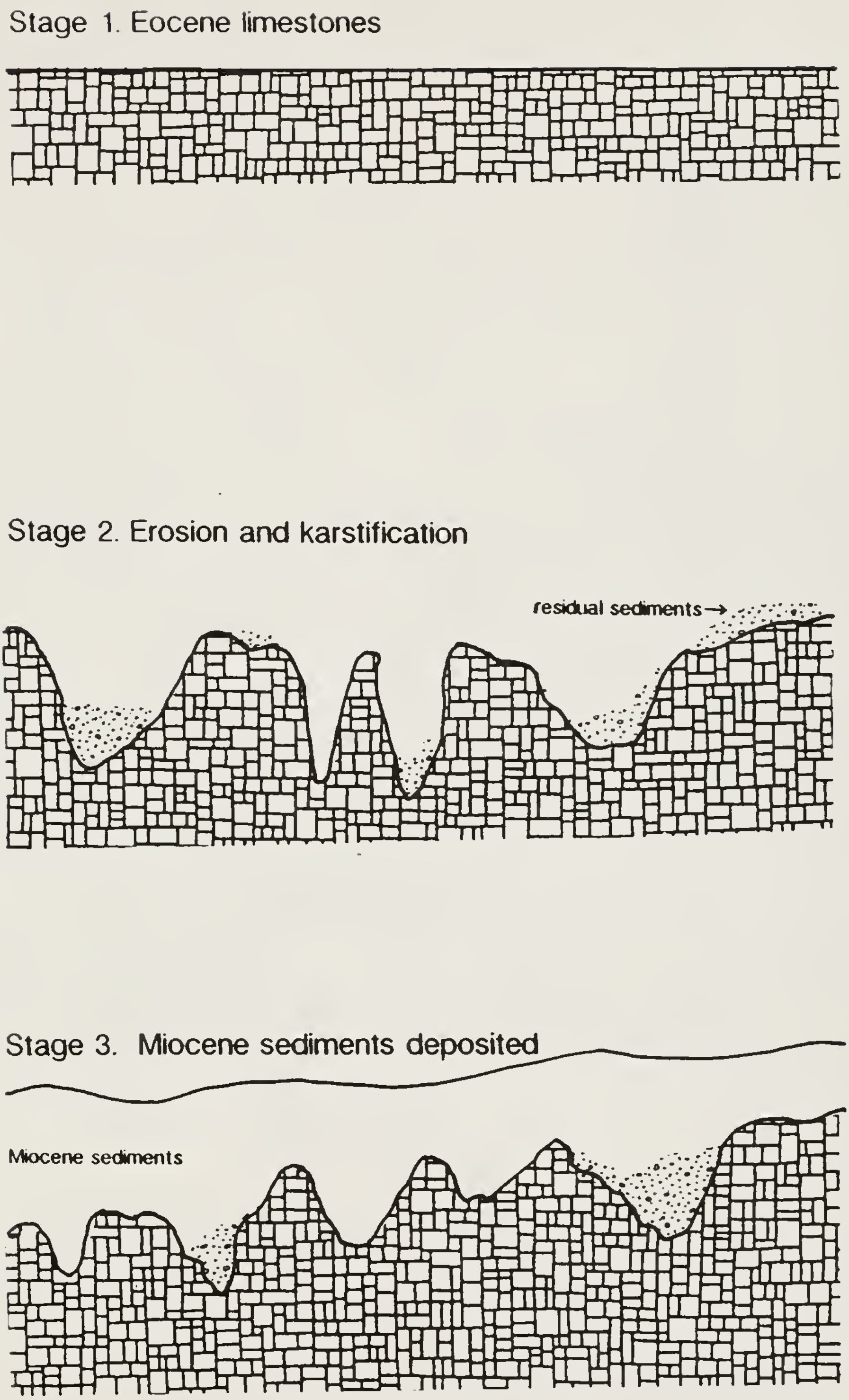
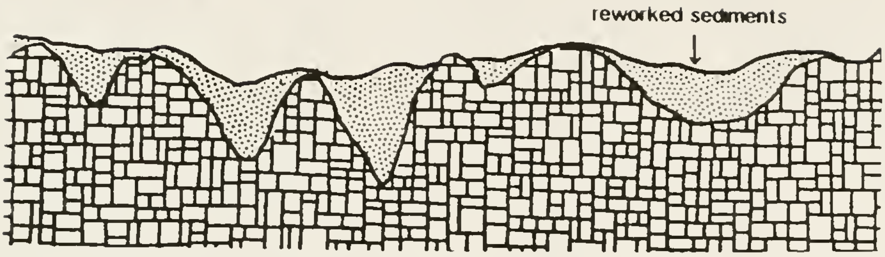
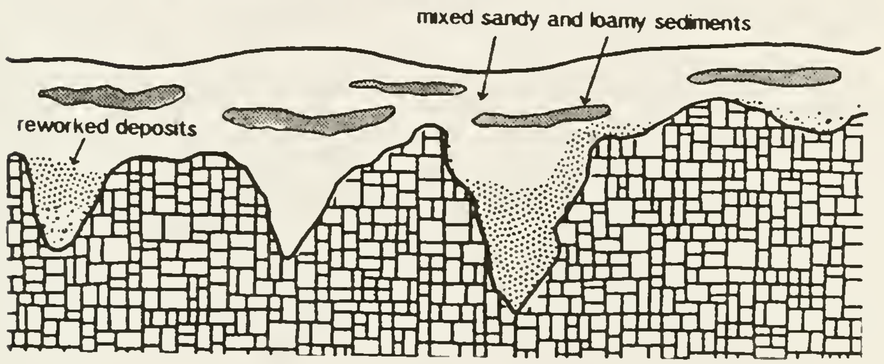


Figure 4-5. Generalized landscape evolution model for the Chiefland Limestone Plain.

Stage 4. Uplift, erosion, and karstification



Stage 5. Plio-Pleistocene sediments deposited



Stage 6. Holocene

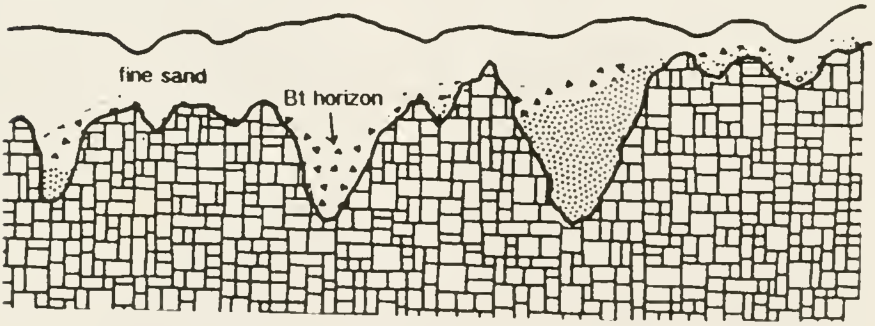


Figure 4-5--continued.

sediments were sandy to loamy, white (10YR 8/1) to brownish-yellow (10YR 6/8) in color, and low in TP. Holocene sediments were composed mostly of fine sands that had filled local depressions due to karst activity and/or were accumulated by eolian processes.

The Ocala Group Limestones formed the base strata for the development of the landscape evolution model (Fig. 4-5, stage 1). Vernon (1951) reported that as a group, the Ocala Group Limestones were > 95% $CaCo_3$ and, upon weathering, would leave little residue.

A period of erosion and karstification followed after which was deposited the Miocene sediments (Fig. 4-5, stage 2 and 3). The Miocene sediments were deposited on a well-developed karst landscape. The sediments were distributed across the landscapes and in depressions and solution pipes. The sediments were subsequently uplifted and eroded with continued karstification (Fig. 4-5, stage 4). Phosphates were concentrated in the eroded and reworked sediments by weathering processes (Altschuler, 1965). Landscape inversion may have also occurred in some areas. The Miocene sediments that had been deposited or eroded into solution features now formed an aquiclude that slowed the denudation rate of the underlying limestones. Newly exposed limestones were removed and new solution features were created which in turn were filled with sediments during the Pleistocene.

Multiple sea level changes (Fig. 4-5, stage 5) during the Pleistocene reworked and deposited both old and new sediments leveling the topography. After the retreat of the last Pleistocene sea from the CLP, soil forming processes and karstification were initiated and have continued. The present topography reflects little of the paleo-karst features (Fig. 4-5, stage 6), as shown in Figs. 3-13 and 3-14. The present surface of the CLP was considered young and immature by White (1970). He attributed the featureless nature of the CLP to insufficient time for significant landscape evolution.

Time-soil sequence model

A summary of the lithological discontinuities as determined using laboratory data are presented in Table 4-13.

Eocene-aged parent materials. The R horizons in the Bushnell and Shadeville soils were correlated as the Ocala Group Limestones. The topography of the R horizons, in the QP, was presented in Fig. 3-16. The R horizons were > 98.5% $CaCo_3$. Williams et al., (1977) reported that the Ocala Group Limestones in western Alachua County were also > 98.5% $CaCo_3$. The amount of insoluble residues available for soil formation, in the QP (Table 4-8), were used to calculate theoretical limestone denudation rates.

The limestone denudation rate based on the Corbel equation (White, 1984) was approximately 1 m of limestone

Table 4-13. Summary of lithological discontinuities as determined using laboratory data for the soils at the Quincey Plot.

Soil	Horizon#	Soil	Horizon#
Otela	Ap1	Shadeville	Ap1
	Ap2		Ap2
	AE		E1
	E1		E2
	E2		Bt1
	E3		Bt2
	Bt1		---
	Bt2		2Bt3
	*---		2Bt4
	2Bt3		---
	---		3R
	1601		
Pedro	Ap	Bushnell	Ap1
	E		Ap2
	Bt		---
	---		2Bt1
	2C		2Bt2
Pedon 12,0	Ap1	Pedon 14,10	Ap1
	Ap2		Ap2
	C1		---
	C2		A
	C3		Ab
	C4/Ab		Eb
	Ab1		Eb/Btb
	Ab2		Eb/Btb
	C'1		
	C'2		

	C'3		

	1201		

	1202		

	1203		

	1204		

Samples taken greater than 2 m below the surface were given a numeric code.
* Lithological discontinuities.

every 31,000 to 40,000 years. The Corbel equation as given by White (1984) is presented below

$$X=(4*E*T)/100 \qquad [1]$$

where X is the karst denudation rate ($m^3 km^{-2} yr^{-1}$), E is the precipitation (dm), and T is mean water hardness ($mg\ l^{-1}$). The E factor was corrected to account for evapotranspiration losses as suggested by White (1984). Water hardness data collected at Manatee Springs, Florida (Rosenau et al., 1977), were used in calculating the denudation rate for the limestones. Opdyke et al., (1984) reported a denudation rate of 1 m of limestone every 38,000 years based on water data collected from springs throughout north-central Florida.

Using a denudation rate of 1 m of limestone every 40,000 years with an insoluble residue of 1.5%, 1.5 cm of insoluble residue could be expected every 40,000 years. Assuming 125,000 years (Matthews, 1973; Shackleton and Opdyke 1973) of terrestrial exposure since the last Pleistocene sea retreated from the CLP, approximately 5 cm of insoluble residue could have formed. The phosphatic clays that capped the limestones in the QP (Figs. 3-15 and 3-16), would probably have reduced the denudation rate of the limestone even more. Based on the insoluble residues of the QP limestones, an initial average sand content would be 17% and the average clay content, 76%. The sand fraction was dominantly quartz.

The clay fractions of the insoluble residues were mostly smectite and apatite with trace amounts of kaolinite. The clay mineralogy of the insoluble residues were similar to findings reported for recent carbonate sediments collected in the Gulf of Mexico (Manker and Griffin, 1971). Smectite and chlorite were the dominant clay-sized insoluble residues of recent carbonate sediments collected in Florida Bay, with illite and kaolinite occurring in small quantities.

Phosphorus minerals are not common in the Ocala Group Limestones. The apatite in the QP limestones was probably formed as a secondary weathering product. Phosphorous was supplied from the overlying clayey sediments to the upper layers of the limestone via watertable fluctuations.

The coarse clay fractions of the insoluble residues was dominantly apatite and contained little kaolinite. Kaolinite, occurring with or without HIV, was a dominant component of the coarse clay fractions of the overlying materials. Therefore, soil clays forming from the insoluble residues of the Ocala Group Limestones would have to undergo (a) transformations from smectite to kaolinite, (b) clay-sized transformations of kaolinite from fine to coarse, and (c) additional transformations to HIV, since mica and vermiculite were not detected in the insoluble residues. Harris et al., (1988) reported that HIV or its precursor may have been introduced into Florida soils by eolian processes.

Soil stratigraphy indicated that the fine sand and R horizons of Sequence 3 soils (Fig. 4-4) were not related. This was also supported by the insoluble residue data. The insoluble residues averaged 17% sand and the sand content in the overlying horizons ranged from 42.0 to 98.2% (Table 4-3).

The Pedro soil may represent the only soil in the QP that was formed in-situ as a residual weathering product, but the laboratory data did not support this. The Jonesville soils (Chapter 2) were similar to the Pedro soils, but the Bt horizons above the R horizons were probably not formed in residuum either. The limestone insoluble residues were, (a) probably eroded as they were formed and concentrated in the cracks and fractures of the irregular limestone surface and possibly removed via groundwater conduits, and/or (b) mixed into overlying sediments.

<u>Miocene-Pliocene parent materials</u>. The 2Bt horizons of the Shadeville and Bushnell soils and possibly the 2C horizon of the Pedro soil were correlated as Miocene sediments. These parent materials were believed to have been reworked during the Pliocene and/or Pleistocene and may have been transported from areas outside of the CLP.

Kaolinite, smectite, apatite, and crandallite were the dominant minerals in the coarse clay fraction in the 2Bt and 2Cr horizons (Table 4-6). Smectite dominated the fine clay

fraction. Smectite has been identified as a dominant component of Hawthorn sediments in north-central Florida (Scott, 1983). Apatite was associated with weathered and reworked residues of the Hawthorn Formation by Altschuler (1965). The Crandallite in the QP soils may have formed by alteration of silicate clays and by direct weathering of apatite (Altschuler et al., 1956; Cathcart and McGreevy, 1959). Crandallite was proposed as an intermediate mineral in the transformation process of apatite to wavellite (Blanchard and Denahan, 1966). Highly weathered phosphorus minerals should contain significant quantities of wavellite. Wavellite was identified in only one horizon; the Bt horizon of the Pedro soil. The wavellite was growing in another mineral, probably crandallite. It's possible that this mineral could be detrital and not formed in-situ. The parent materials of the 2Bt and 2C horizons were probably reworked sediments of the Hawthorn and Alachua Formations, but were not subjected to conditions favorable for the formation of wavellite.

The FC/CC ratio was highest in the 2Bt3 horizon in the Shadeville soil. This could indicate that soil welding had occurred between the 2Bt and overlying Bt horizons. The 2Bt1 horizon of the Bushnell soil also showed a FC/CC ratio that was equivalent to the FC/CC ratio between the E and Bt1 horizons in the Otela soil. This could indicate that a Bt horizon, similar to the Bt horizons in the Otela and

Shadeville soils, was once present in the Bushnell soil but has since been removed or that the FC/CC ratio presented in Table 4-11, was typical for the 2Bt1 horizon. The Ap horizons in the Bushnell soil contained crandallite which was probably detrital.

The parent materials for the 2Bt horizons could have been (a) reworked and transported in either a marine or fresh water environment, (b) formed in-situ as the compacted residues of former sediments that have since been eroded, or (c) filled solution pipes that have since been removed by karstification leaving the clayey materials within the solution pipes to "spread" across the adjacent landscapes. Based on the calculated denudation rates, several meters of limestone could have been removed since the last Pleistocene sea covered the CLP and any sediments that filled the solution features could have been "spread" across the adjacent landscapes.

The 2C horizon in the Pedro soil may have formed as, (a) Eocene limestones that had undergone intense weathering and phosphatization, or (b) limestone and phosphatic rubble that had accumulated during Miocene to Pleistocene times. The sandy clay material in the 2C horizon and the clay of the Bt3 horizon in the Otela soil were believed to have had similar origins. They were brownish yellow (10YR 6/6) in color (which indicated they were more oxidized than the 2Bt horizons), high in TP, and contained crandallite. It was

believed that these horizons represented Pliocene sediments that are similar to the sediments of the Alachua formation (Vernon 1951; Pirkle, 1956).

Pleistocene parent materials. The Pleistocene parent materials were represented by the A, E, C, and Bt horizons of the QP soils (Table 4-12). The topography of the Bt horizons were presented in Fig. 3-14. Laboratory data suggested a pedogenic rather than a geologic origin for the horizons observed. One of the most prominent features was the development of the abrupt boundaries between the E and Bt horizons in the Otela, Shadeville, and Pedro soils. Researchers in Florida have agreed that these abrupt boundaries were pedogenic in origin (Carlisle, 1962; Fiskell and Carlisle, 1963; Cabrera-Martinez et al., 1989a). A classical study by Gamble et al. (1970), also concluded that the boundary between the E and Bt horizons in the Coastal Plain area of North Carolina were formed by pedogenic processes. Questions still remain about the origin of Bt horizons that are overlain by thick (1 to 2 m) sand (Forbes, 1986).

Abrupt boundaries between E and Bt horizons are common in the Alfisols, Spodosols, and Ultisols orders throughout Florida (Carlisle et al., 1988; Carlisle et al., 1989). These soils occurred on various geomorphic surfaces throughout the state. These surfaces ranged in elevation

from less than 3 to 100 m and from Pliocene to late Pleistocene in age.

The pedogenic process or processes that were responsible for these boundaries forms a common thread between these soils regardless of parent materials, biota, time, and topography. Terrestrial climate can be considered as a constant. The pedogenic process must be something that all the soils shared at some point in time during their development. The pedogenic threshold for the start of the process must be of short duration, since abrupt boundaries were observed in soils on the Pamlico terrace and in soils on the Coharie-Okefenokee terrace in Levy County. Differential weathering and in-situ formation or transformations and translocation of soil clays have been the most common pedogenic mechanism given for explaining the formation of argillic horizons in Florida. However, Cabrera-Martinez et al. (1989a) suggested that differential weathering was not a significant process due to the preweathered nature of the parent materials.

Oriented clay on grains, within pores, and clay bridging provided evidence that clay illuviation had occurred in the Bt horizons of the QP soils. Fine clay to total-clay ratios also indicated an accumulation of fine clay in the Bt horizons (Table 4-11).

Soil parent materials on the CLP shared a common alluvial history. Since the sandy and loamy sediments have

been attributed to deposition by Pleistocene seas (Cooke, 1945; Vernon, 1951; Pirkle, 1956; Pirkle, 1957; Cathcart et al., 1959; Pirkle, 1960; Pirkle et al., 1965; Puri et al., 1967; Healy, 1975; Williams et al., 1977; Brooks, 1981; Pirkle et al., 1985), the soil parent materials were considered marine in origin. A mechanism for the pedogenic processes responsible for clay eluviation-illuviation and subsequent formation of the abrupt boundaries is presented below.

The soil parent material was supplied from older reworked sediments from Florida or detrital sediments brought in by ocean currents from other areas. The soil parent material was deposited in an open marine to brackish bay or deltaic environments. The sediments were probably homogeneous to stratified in nature. The clay mineralogy of these sediments were probably similar to the clay mineralogy of recent bottom sediments in the Gulf of Mexico. The source area for these recent bottom sediments were the Mississippi, Mobile, and Appalachicola Rivers which transported large quantities of sediments from the central and southeastern portion of the United States (Griffin, 1962). The sediments derived from the Mississippi River were dominantly smectites; the Appalachicola River sediments were dominantly kaolinite; and the Mobile River sediments were mixed. The Appalachicola sediments were more highly weathered since the sediments were derived from older

Coastal Plain sediments. The Mississippi sediments were younger since they were derived from recently glaciated regions in the United States. The clay mineralogy of the QP soils were very similar to the recent sediments from the Gulf of Mexico. Hydroxy-interlayered vermiculite was not identified in recent Gulf sediments, but its identification may be attributed to the occurrence of HIV as a soil mineral and its unfamiliarity to geologists.

The sediments of the CLP were probably saturated with salts and represented a flocculated system. As the sea retreated and the sediments were exposed to subaerial weathering and fresh water, the salts were leached and dispersion of clays occurred. The clay-sized particles, in the sandy matrix moved rapidly downward until flocculation occurred. Flocculation occurred when salt concentrations were reduced. The amount of downward movement by clay particles was controlled by the clay content of the original sediments and soil hydrology. This mechanism may have initiated the process with differential weathering and in-situ transformations continuing after the cessation of the flocculation-dispersion mechanism. The flocculation-dispersion mechanism would explain the occurrence of abrupt boundaries between different soils on various geomorphic surfaces.

Conclusions

The QP soils represented the dominant soils occurring on the CLP. The soils of the QP were highly variable with respect to soil horizonation and parent materials. Soil parent materials ranged in age from Eocene to Holocene. The Ocala Group Limestones formed the base strata for the development of karst. Miocene to Pliocene sediments were clayey and had high TP contents. Pleistocene sediments were sandy to loamy and had low TP contents. The dynamic processes associated with karst and sea-level fluctuations created a complex system of soils and landscapes.

Thin sections, sand ratios, and clay ratios all indicated a pedogenic origin for the Bt horizons in the Otela, Shadeville, and Pedro soils. The 2Bt horizons in the Shadeville and Bushnell soils were not formed from the overlying or underlying materials in those soils. Pedons 12,0 and 14,10 were formed by local filling of sinkholes and depressions during the late Pleistocene or Holocene. The Candler soil formed in sediments that had collapsed into a sinkhole with subsequent formation of lamellae. This event was substantiated by the presence of sandy loam masses that were distributed throughout the E/Bt horizon.

Kaolinite, HIV, and quartz were the dominant coarse clay-sized minerals in the A, E, and Bt horizons. Smectite and kaolinite dominated the fine clay. The coarse clay-

sized minerals identified in the 2Bt horizons were kaolinite, smectite, apatite, and crandallite. Apatite and crandallite were believed to have formed secondarily in the soil horizons of the QP.

CHAPTER 5
GENERAL CONCLUSIONS

The soils on the Chiefland Limestone Plain (CLP) have been shaped by sea-level fluctuations and karst processes. The present surface does not reflect the spatial variations of the subsurface horizons or limestone topography. The soils and landscapes of the CLP do not covary in an explainable systematic way. Grid mapping techniques were required to delineate the soil map units on the CLP. A refined mapping method, the flex-grid mapping method, and new map unit concept, the intriplex, were introduced as a result of this research.

The flex-grid mapping method required fewer observations than the traditional grid mapping method and was, therefore, more efficient. The intriplex map unit was designed to properly describe the soils and landscapes of the bare karst areas of west-central Florida. However, the intriplex map unit should have nationwide use in areas where soils and landscapes appear to occur independently at the scale of mapping. Ground-penetrating radar (GPR) proved to be a useful and valuable tool to qualify and quantify the soils on the CLP.

The soils in a 4-ha plot (Quincey plot, QP) were studied in great detail in order to determine the limitations of using GPR data in identifying soil types and soil spatial characteristics. Soil color, texture, and drainage could not be readily determined using the GPR. Phosphatic and carbonatic materials were differentiated using GPR data based on the presence or absence of voids in the materials. The 120-MHz antenna had a subsurface resolution of approximately 34 cm, which was less than theoretically possible. A 25% error rate was encountered in the identification and classification of the soils on the QP. The identified subsurface radar interfaces indicated that most of the karst features in the QP had formed before the present surface was deposited. A nearest neighbor analysis of the soils indicated few relationships between the soils and landscapes.

The soils in the QP were formed by pedogenic processes. Parent materials from several geologic times and sources were reworked and deposited on a paleo-karst surface. The Eocene Group Limestones formed the base strata for karst development. Reworked phosphatic clays derived during the Miocene and Pliocene epochs were transported and deposited across the CLP. Deposited Pleistocene sands and clays leveled the karst topography. Local karst activity has altered the topography and moved the sediments to create local areas of Holocene-aged soils. A flocculation-

dispersion process was proposed as a mechanism in the formation of abrupt boundaries between E and Bt horizons. This process would be independent of landscape position.

The experience and knowledge gained from this research has already proved beneficial in the identification and understanding of the soils for the progressive soil surveys of Gilchrist, Dixie, Lafayette, Suwannee, and Taylor Counties. The information was also used during the update of the Marion County soil survey. These counties had similar karst areas where soils and landscapes appeared to occur randomly.

The bare karst areas shown in Fig. 1-4, will also benefit from this research. Agricultural and urban development pressures will fuel concerns over groundwater contamination in this sensitive area where the Floridan aquifer is close to the surface. Environmental models are being developed that require more detailed soils information and modelers must be aware of the spatial variability of the soils in this bare karst area. Soil genesis studies help us to better understand the processes responsible for the soils and the complex interactions that could occur when the soil system interacts with human-introduced substances.

This research project was exploratory in nature and several possible avenues of future soils research are possible. A foundation of basic information about the soils and landscapes of the bare karst region of west-central

Florida has been provided. Continued testing and fine-tuning of the flex-grid mapping method and intriplex map unit concept should be pursued. Geostatistics might better explain the spatial characteristics of the soils and landscapes on the CLP. Cluster analysis and principle component analysis might better explain the relationships between soil horizons and their genesis. A study of soils in the other physiographic areas of Levy County might help explain the relationships between time, parent materials, and pedogenic processes.

APPENDIX
PEDON DESCRIPTIONS

Pedon: 0,16
Series: Otela
Described by: W.E. Puckett and R.W. Arnold.
Date: February 4, 1986.

HORIZON	DEPTH (cm)	DESCRIPTION
Ap1	0-18	Very dark gray (10YR 3/1) fine sand, gray to light gray (10YR (10YR 6/1) dry, very dark grayish brown (10YR 3/2) rubbed; weak medium and fine subangular blocky structure parting to weak medium granular structure; very friable; many fine and medium roots and few coarse roots; clear smooth boundary.
Ap2	18-36	Very dark gray (10YR 3/1) fine sand, gray to light gray (10YR 6/1) dry, and very dark grayish brown (10YR 3/2) rubbed; weak medium and fine subangular blocky structure parting to weak medium granular structure; very friable; common fine roots and few medium roots; clear smooth boundary.
AE	36-59	Grayish brown (10YR 5/2) fine sand, common medium distinct pale brown (10YR 6/3) mottles; tubular krotovina, 10 cm long and 5 cm wide, filled with very pale brown (10YR 7/3) fine sand; weak medium and fine subangular blocky structure parting to weak medium granular structure; very friable; common fine roots; few fine charcoal; clear smooth boundary.
E1	59-88	Very pale brown (10YR 7/3) fine sand, common medium distinct white (10YR 8/2) and yellow (10YR 7/6) mottles; three oval krotovinas, 5 to 8 cm in diameter, filled with light brownish gray (10YR 6/2) fine sand; weak medium and fine subangular blocky structure parting to weak medium granular structure; very friable; common

Pedon 0,16--Continued.

		fine roots; clear smooth boundary.
E2	88-119	Mixed very pale brown (10YR 7/3) and white (2.5Y 8/2) fine sand, few medium distinct yellow (10YR 7/6) mottles around roots; oval krotovinas, 1 to 6 cm in diameter, filled with light brownish gray (10YR 6/2) fine sand; weak medium and fine subangular blocky structure parting to weak medium granular structure; very friable; few fine charcoal; common fine roots; clear smooth boundary.
E3	119-138	White (10YR 8/1) fine sand, common medium distinct yellow (10YR 8/6) mottles and few medium distinct yellow (10YR 7/6) mottles around roots; oval krotovinas, 1 to 6 cm in diameter, filled with light brownish gray (10YR 6/2) fine sand; weak medium and fine subangular blocky structure parting to weak medium granular structure, very friable; few fine charcoal; common fine roots; abrupt wavy boundary.
Bt1	138-153	Light yellowish brown (10YR 6/4) very fine sandy loam, few fine distinct strong brown (7.5Y 5/8) mottles; moderate medium subangular blocky structure; friable; common fine roots; clear irregular boundary.
Bt2	153-193	Light yellowish brown (10YR 6/4) very fine sandy loam, common medium distinct light gray (10YR 7/2) and brownish yellow (10YR 6/8) mottles; moderate medium and coarse subangular blocky structure; friable; few very fine roots; clear wavy boundary.

Pedon 0,16--Continued.

Bt3	193-200	Brownish yellow (10YR 6/6) sandy clay loam, few medium distinct grayish brown (10YR 5/2) mottles; weak medium prismatic parting to moderate medium and coarse subangular blocky structure; friable; few very fine roots.
R	318	Limestone.

Pedon: 2,4
Series: Shadeville
Described by: R.W. Arnold, W.G. Harris, D. Slabaugh, C.Wettstein, and W.E. Puckett.
Date: February 4, 1986.

HORZON	DEPTH (cm)	DESCRIPTION
Ap1	0-16	Dark gray (10YR 4/1) fine sand, gray to light gray(10YR 6/1) dry, dark gray (10YR 4/1) rubbed; weak medium subangular blocky structure parting to weak medium granular structure; very friable; many fine and very fine roots and few medium roots; abrupt irregular boundary.
Ap2	16-28	Dark gray (10YR 4/1) fine sand, gray to light gray (10YR 6/1) dry, dark gray (10YR 4/1) rubbed; weak medium subangular blocky structure parting to weak medium granular structure; very friable; common fine and very fine roots and few medium roots; abrupt wavy boundary.
E1	28-51	Light brownish gray (10YR 6/2) fine sand, common medium faint pale brown (10YR 6/3) mottles; weak medium subangular blocky structure parting to weak medium granular structure; very friable; few fine and very fine roots; clear smooth boundary.
E2	51-74	Very pale brown (10YR 7/3) fine sand, few fine distinct light yellowish brown (10YR 6/4) mottles around roots, common pockets of white (10YR 8/1) uncoated sand grains; weak medium subangular blocky structure parting to weak medium granular structure; very friable; few fine and very fine roots; abrupt smooth boundary.
Bt1	74-112	Brown (10YR 5/3) very fine sandy loam; moderate medium subangular

Pedon 2,4--Continued.

		blocky structure; friable; lightly sticky; non-plastic; few fine roots; clear smooth boundary.
Bt2	112-145	Brown (10YR 5/3) very fine sandy loam, common fine faint yellowish brown (10YR 5/4) mottles; moderate medium subangular blocky structure; friable; slightly sticky; non-plastic; few fine roots; abrupt wavy boundary.
2Bt3	145-183	Light brownish gray (2.5 Y 6/2) sandy clay loam, common fine distinct yellowish brown (10YR 5/8) mottles; moderate coarse subangular blocky structure; firm; sticky; few fine and very fine roots; gradual wavy boundary.
2Bt4	183-194	Grayish brown (2.5Y 5/2) clay, few fine prominent strong brown (7.5 YR 5/6) mottles; common discontinuous dark gray (10YR 4/1) streaks, 1 to 5 mm, above limestone; moderate coarse subangular blocky structure; firm; sticky; plastic; few fine and very fine roots; abrupt wavy boundary.
3R	194	White (N8/0) hard limestone.

Pedon: 2,21.
Series: Pedro Variant.
Described by: W.E. Puckett, W.G. Harris, and M.E. Collins.
Date: January 30, 1986.

HORZON	DEPTH (cm)	DESCRIPTION
Ap	0-18	Dark gray (10YR 4/1) fine sand, gray to light gray (10YR 6/1) dry, very dark gray (10YR 3/1); circular krotovina, 5 cm in diameter, filled with dark grayish brown (10YR 4/2) fine sand; weak medium granular structure; very friable; many medium and fine roots; abrupt smooth boundary.
E	18-38	Very pale brown (10YR 7/4) fine sand; single grained; loose; common medium and fine roots; clear wavy boundary.
Bt	38-49	Brownish yellow (10YR 6/6) sandy clay loam; moderate medium subangular blocky structure; friable; common fine roots; clear irregular boundary.
2C	49-200	White (10YR 8/2) phosphatic material, intermingled brownish yellow (10YR 6/6), gray to light gray (10YR 6/1), and light yellowish brown (10YR 6/4) sandy clay; structureless; phosphatic material firm to very firm; sandy clay material friable; few fine roots along phosphatic material and soil interface.

Pedon: 10,10.
Series: Bushnell.
Described by: W.E. Puckett, M.E. Collins, and W.G. Harris.
Date: January 30, 1986.

HORZON	DEPTH (cm)	DESCRIPTION
Ap1	0-19	Dark gray (10YR 4/1) fine sand, gray to light gray (10YR 6/1) dry, very dark gray (10YR 3/1) rubbed; weak fine granular structure; very friable; many medium and fine roots; gradual smooth boundary.
Ap2	19-34	Dark gray (10YR 4/1) fine sand, gray to light gray (10YR 6/1) dry, very dark gray (10YR 3/1) rubbed; weak fine and medium subangular blocky structure; very friable; common medium and fine roots; abrupt wavy boundary.
2Bt*	34-96	Mixed brownish yellow (10YR 6/6), yellowish brown (10YR 5/8), gray (10YR 5/1), and gray to light gray (10YR 6/1) sandy clay; moderate medium and coarse subangular blocky structure; firm; plastic; sticky; few fine roots; abrupt irregular boundary.
3Cr	96-126	White (N8/0) soft limestone; firm to extremely firm; gradual wavy boundary.
3R	126	White (N8/0) hard limestone.

* Horizon was subsampled.

Pedon: 12,0.
Series: None established.
Described by: W.E. Puckett, R.W. Arnold, and C.W. Wettstein.
Date: Febuary 4, 1986.

HORZON	DEPTH (cm)	DESCRIPTION
Ap1	0-18	Very dark gray (10YR 3/1) fine sand, gray to light gray (10YR 6/1) dry, and grayish brown (10YR 5/2) rubbed; weak fine and medium subangular blocky structure parting to moderate medium granular structure; very friable; many fine and few medium roots; gradual wavy boundary.
Ap2	18-37	Very dark grayish brown (10YR 3/2) fine sand, light gray (10YR 7/1) dry, and dark gray (10YR 4/1) rubbed, few coarse distinct reddish brown (2.5YR 5/4) mottles; weak medium subangular blocky structure; very friable; common fine and medium roots; abrupt smooth boundary.
C1	37-64	Light brownish gray (10YR 6/2) fine sand, few fine distinct yellowish brown (10YR 5/6) mottles; common pockets of light gray (10YR 7/1) uncoated sand grains; weak fine and medium subangular blocky structure; very friable; common fine and medium roots; diffuse wavy boundary.
C2	64-85	Light brownish gray (10YR 6/2) fine sand, few fine distinct yellowish brown (10YR 5/6) mottles; common pockets of light gray (10YR 7/1) uncoated sand grains; nearly vertical (80 degrees) krotovina extending upward from lower horizons, 1 to 3 cm in diameter, filled with dark brown (10YR 3/3) fine sandy loam; weak fine and medium subangular blocky structure; very friable; few medium roots; gradual smooth boundary.

<u>Pedon 12,0--Continued</u>.

C3	85-106	Mixed light gray (10YR 7/1) and light brownish gray (10YR 6/2) fine sand, common medium distinct yellowish brown (10YR 5/6) and brownish yellow (10YR 6/6) mottles around roots; krotovinas extending upward from lower horizons, 1 to 3 cm in diameter, filled with dark brown (10YR 3/3) fine sandy loam; weak fine and medium subangular blocky structure; very friable; few fine roots; gradual smooth boundary.
C4/Ab	106-112	Mixed very pale brown (10YR 7/3), brown (10YR 4/3), yellowish brown (10YR 5/6), and reddish yellow (7.5YR 6/8) fine sand; krotovina extending upward from lower horizons, 1 to 3 cm in diameter, filled with dark brown (10YR 3/3) fine sandy loam; weak medium subangular blocky structure; very friable; few fine roots; abrupt smooth boundary.
Ab1	112-119	Mixed dark brown (10YR 3/3) and brown (10YR 4/3) loamy fine sand, few fine faint dark yellowish brown (10YR 4/4) mottles; moderate medium subangular blocky structure; friable; few fine roots; gradual smooth boundary.
Ab2	119-137	Very dark grayish brown (10YR 3/2) very fine sandy loam, few fine faint very dark gray (10YR 3/1) mottles; moderate medium subangular blocky structure; friable; few fine roots; gradual wavy boundary.
C'1	137-149	Upper six centimeters very dark grayish brown (10YR 3/2), dark grayish brown (10YR 4/2), and very pale brown (10YR 7/3) stratified loamy fine sand; lower six centimeters light gray (10YR 7/2) very fine sand, common fine

12.0--Continued.

		prominent strong brown (7.5YR 5/6) mottles; weak fine and Pedon medium subangular blocky structure; very friable; few fine roots; gradual wavy boundary.
C'2	149-156	Dark grayish brown (10YR 4/2) very fine sand, common fine prominent brownish yellow (10YR 6/6), and strong brown (7.5YR 5/6) mottles; common pockets of white (10YR 8/1) uncoated sand grains; weak fine and medium subangular blocky structure; very friable; few fine roots; gradual wavy boundary.
C'3	156-200	White (10YR 8/1) fine sand, few fine prominent strong brown (7.5YR 5/6) mottles; single grained; loose.

Pedon: 14,10.
Series: None established.
Described by: W.E. Puckett, M.E. Collins, and W.G. Harris.
Date: January 30, 1986.

HORZON	DEPTH (cm)	DESCRIPTION
Ap1	0-19	Black (10YR 2/1) loamy fine sand, gray (10YR 5/1) dry, black (N/1) rubbed; weak fine and medium granular structure; friable; common fine, medium, and coarse roots; clear smooth boundary.
Ap2	19-37	Black (10YR 2/1) loamy fine sand, gray to light gray (10YR 6/1) dry, black (N/1) rubbed; weak fine and medium granular structure; friable; common fine roots; clear smooth boundary.
A	37-62	Very dark gray (10YR 3/1) fine sand; horizontal strata of gray to light gray (10YR 6/1) fine sand; weak thick platy structure; friable; few fine roots; gradual wavy boundary.
Ab	62-104	Grayish brown (10YR 5/2) fine sand; circular krotovina, 3 cm diameter, filled with light gray (10YR 7/1) fine sand; weak fine subangular blocky structure; friable; few fine charcoal; gradual wavy boundary.
Eb	104-146	Light gray (10YR 7/2) fine sand; single grained; loose; few fine roots; few fine charcoal; gradual wavy boundary.
Eb/Btb*	146-200	White (10YR 8/1) fine sand; single grained; loose; five light brownish gray (10YR 6/2) loamy fine sand lamellae about 2 to 5 mm thick and discontinuous throughout the horizon; structureless; very friable; few fine roots.

* Horizon was subsampled.

Pedon: 18,18.
Series: Candler.
Described by: W.E. Puckett, M.E. Collins, and W.G. Harris.
Date: January 30, 1986.

HORZON	DEPTH (cm)	DESCRIPTION
Ap1	0-29	Dark grayish brown (10YR 4/2) fine sand, gray (10YR 5/1) dry, very dark grayish brown (10YR 3/2) rubbed; weak fine granular structure; very friable; common fine roots; clear wavy boundary.
Ap2	29-37	Very dark gray (10YR 3/1) fine sand, gray to light gray (10YR 6/1) dry, very dark grayish brown (10YR 3/2) rubbed; weak fine granular structure; very friable; many medium and fine roots; abrupt smooth boundary.
AE	37-72	Brown (10YR 5/3) fine sand, common fine distinct light gray (10YR 7/2) pockets of uncoated sand grains; large elliptical krotovina, 30 cm long and 9 cm wide, filled with dark grayish brown (10YR 4/2) fine sand; weak fine and medium subangular blocky structure parting to weak fine granular; very friable; few fine roots; common medium charcoal; gradual wavy boundary.
E1	72-122	Very pale brown (10YR 7/4) fine sand, common medium distinct light gray (10YR 7/2) pockets of uncoated sand grains, common medium distinct yellow (10YR 7/8) mottles; tubular krotovina, 15 cm long and 3 cm diameter, filled with light brownish gray (10YR 6/2) fine sand; weak medium subangular blocky structure; very friable; few fine roots; common fine charcoal; gradual wavy boundary.

Pedon 18,18--Continued.

E2	122-182	White (10YR 8/2) fine sand, common medium distinct very pale brown (10YR 7/4), and few fine distinct light gray (10YR 7/2) mottles; single grained; loose; few fine roots; gradual wavy boundary.
E/Bt	182-200	White (10YR 8/2) fine sand, few fine prominent yellow (10YR 7/8) mottles; single grained; loose; four light yellowish brown (10YR 6/4) loamy fine sand lamellae about 2 to 10 mm thick and discontinuous throughout the horizon; structureless; very friable; few fine roots.

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BIOGRAPHICAL SKETCH

William Edward Puckett, son of George Edward Puckett and Edna P. Puckett, was born on August 4, 1958, in Donaldsonville, Georgia. Mr. Puckett graduated from Cottonwood High School in Cottonwood, Alabama, in 1976. Mr. Puckett received a Bachelor of Science degree and a Master of Science degree in agronomy from Auburn University, Auburn, Alabama, in 1981 and 1983, respectively.

Mr. Puckett attended Clemson University during the fall of 1983. In December 1983 Mr. Puckett moved to Florida and started working for the Soil Conservation Service, where he is presently employed. Mr. Puckett was a graduate research assistant in the Soil Science Department at the University of Florida from August 1986 to February 1988.

Mr. Puckett is married to Elizabeth Ann Hunt-Puckett and has a son Ashton Hunt.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Mary E. Collins

Mary E. Collins, Chair
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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